metal atment

Vol. 28 : No. 189 JUNE, 1961 Price 2/6

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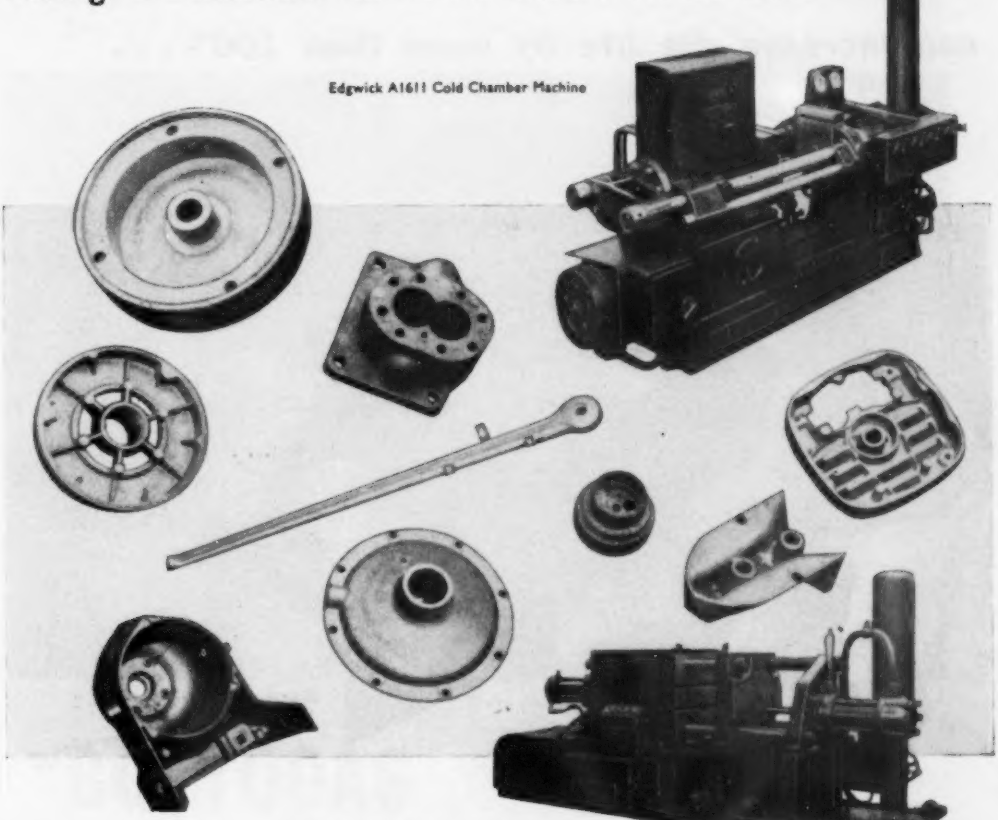

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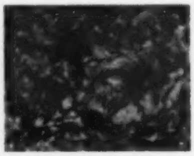
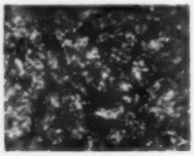
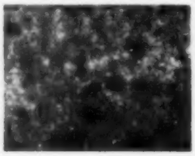


18/8 Stainless Steel surface after two hours in Nitric Hydrofluoric Acid bath. Over pickling has resulted in etched crystalline surface.



18/8 Stainless Steel surface after two hours in Ferric Sulphate Hydrofluoric Acid bath. Over pickling has had no effect on the metal surface.

× 40



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metal treatment
and Drop Forging

CONTENTS

This journal is devoted to metals—ferrous and non-ferrous—their manufacture, properties, heat treatment, manipulation, testing and protection, with research work and development in all these fields

Chemists and alchemists

EVER since the days of the alchemist it has been difficult to draw a sharp dividing line between the interests of the chemist and the metallurgist. Although recent research indicates that the origins of alchemy may well be sought in the sacred rites peculiar to archaic metallurgy, it has, in fact, been the chemist who has claimed lineal descent from the practical alchemist. Indeed, there is good reason for this. Until the end of the 16th century, alchemists were almost the only laboratory workers in any part of the globe and, whatever we may now think of their theories, a list of their chemical discoveries and evolving technical methods makes impressive reading. Alchemical techniques gradually began to be taken over during the course of the 16th century in Europe, first by the pharmacists and then by the early chemists in our modern understanding of the term.

Perhaps, therefore, it is not too fanciful to see significance in the fact that the 1960 report of the National Chemical Laboratory has for its cover illustration D. Tenier's *Alchymist*. It is true that the old alchemist could confine himself almost exclusively to the study of metallic substances, whereas the modern chemist has also the vast field of organic chemistry to cover, but a surprisingly high proportion of the 1960 report is concerned with chemical problems relating to metals. Metallurgists working in related fields need to keep aware of what investigations by chemists may have to offer in their subject. Examples of such possibilities from the present report are the prevention of corrosion in water and soils, study of the behaviour of metals in contact with solutions at high temperatures and pressures, and high-degree purification of rare elements.

One of the most exciting developments of recent years is the new research technique of field emission or field ion microscopy (METAL TREATMENT, September, 1960). This technique is being applied at the Laboratory by a research group under the leadership of the Director, Dr. J. S. Anderson, PH.D., F.R.S. Work has been started on the study of physical processes and chemical reactions on absolutely clean metallic surfaces, using the field emission microscope. The intense electric field produced by applying a potential of a few kilovolts to a point of tungsten, platinum or other metal, 1,000–2,000 Å in radius, draws a flux of electrons from the tip. Such a small tip is usually a single crystal; in ultra-high vacuum it can be freed from all chemisorbed gas. The electron emission depends on the field strength (and hence the local contour of the tip) at each point and on the work function of the metal. The local contour is modified by migration or displacement of atoms in the surface layers; the work function is modified by crystal orientation and, profoundly, by chemisorbed layers. Hence the image produced on a fluorescent screen—in essence a stereographic projection of the single crystal tip—reflects the changes brought about by physical and chemical adsorption, surface diffusion, nucleation and growth of new phases, etc., and should reveal something of the detailed topochemistry of surface processes. In continuation of work started in the Director's laboratory at the University of Melbourne, the condensation, migration, nucleation and penetration of copper, nickel and other metals evaporated on to a tungsten surface are at present being investigated. Work has been started on the related and very powerful technique of field ion microscopy, which is capable of imaging individual atoms on the metal surface. The object is to study the nature of the surface sites involved in the chemical absorption of oxygen and other reactive gases, and the subsequent processes in the first stages of heterogeneous reactions.

The important part played by chemistry in the metals field today is obvious; the debt which chemistry itself owes to the ancient art of metallurgy is less well known. Perhaps the new field of nuclear metals will enable the metallurgist, like the alchemist of old, to make a further contribution to the science of chemistry.

Russian forging journal

Abstracts from the Russian forging journal—'Kuznechno-Shtampovochnoe Proizvodstvo,' November, 1960, **2.** *This is the second year of this journal devoted specifically to forging. Short abstracts of the more important articles are given in* METAL TREATMENT *each month*

Choice of a rational technique of hot-stamping conical pinion forgings. B. S. PEREVOZCHIKOV and V. F. KOVALENKO. Pp. 1–6.
Experiments were conducted on various heavy forging presses with different techniques to rationalize mass production (500,000 units per annum) of back-axle leading pinions for the GAZ-51 automobile. Best results were obtained on a 6,300-*tonne* press in four passes (upsetting, preliminary forging, final forging and piercing). Teeth are preformed during stamping, and particular attention was given to location of the flash for gripping and transporting the forgings, and the possibility of maximum automation.

Hot rolling of long, ccarse pitch threads on hollow components. M. V. VASIL'CHIKOV and M. M. VOLKOV. Pp. 7–10.
Production of hollow components with an external thread by oblique skew rolling of hollow-cast billets in two-roll mill affords considerable saving in labour and metal costs, the surface fibres of the metal are oriented along the outline of the thread, and the structure of the cast metal is improved, becoming fine-grained but remaining fibrous, with an improvement in mechanical properties.

Development of a production technique for hollow axles. M. YU. SHIFRIN, YU. E. KOVALENKO, B. P. KOLESNIK, N. K. POLYAKOVA and A. M. KHARKHORIN. Pp. 11–15.
Research work shows that it is possible to produce hollow axles for railway rolling stock from hollow-rolled billets by oblique skew rolling in a three-roll mill and subsequent forging of the ends in hydraulic presses. Properties of the finished axles are entirely satisfactory, and fatigue and service tests have produced good results.

Effect of dynamic loading on the properties of thin sheet steel for deep drawing. B. A. SHCHEGLOV. Pp. 15–18.
Comparison of the results of the author's experiments with those previously obtained by other research workers permits these conclusions to be reached. Under conditions of both monoaxial and biaxial extension the effect of the strain rate is expressed in an increase in the resistance of the material, so that the stress-deformation dynamic load diagram lies higher than the static. The value most subject to the strain rate is the yield point; on increasing the strain rate from 10^{-5} to 1sec.^{-1} the yield point rises by 50%. The u.t.s. also rises but to a much smaller extent. No noticeable effect is exerted on the nature of the distribution of the deformations on the surface of a specimen during biaxial plastic extension of sheet material not having a flow area. The degree of final deformation is also independent of the flow rate during biaxial extension.

Hot stamping of components from case-hardened billets. P. A. IVANOV. Pp. 18–21.
Experiments were conducted in the forging of billets after case-hardening at 1,100–1,200°C. for 1 h. (depth of hardening 1·5–2 mm.) to produce piston pins.

Research into metal flow during the stamping of hollow forgings of complicated shapes at the GKM. L. A. RABINOVICH. Pp. 21–25.

Minimum forging tapers. A. N. BRYUKHANOV. Pp. 25–27.
Extensive production experience in the use of the new method of calculation of minimum tapers described shows considerable saving in metal through reduction in flash.

The effect of preliminary cold working on the real resistance to deformation during cold bulk stamping and upsetting. V. A. KROKHA. Pp. 27–30.
To determine the force required for deformation it is necessary to know the real resistance to deformation based on hardening curves. This applies especially to cold-drawn material. Hot-rolled bars were cold drawn with up to 47% deformation, and the real resistance to deformation determined. This was then related to the hardening curves.

Movable safety devices on cold-stamping presses. L. S. SAGATELYAN. Pp. 30–35.

Calibration of a 4,000-tonne, *crank-drive* NKMZ *hot-forging press by means of crusher gauges.* V. F. KOVALENKO, S. S. SANNIKOV and P. I. STRUKOV. Pp. 35–37.
Calibration of presses and press force indicators.

A device for control and protection of the moving cross head of hydraulic presses against canting. R. M. LISNYANSKII. Pp. 38–40.

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University of Oxford

Photograph by courtesy of the 'Architect and Building News'

Department of Metallurgy

It is perhaps not yet fully appreciated by industry what excellent facilities are now available at our older universities for the training of metallurgists. The outstanding student who could usefully absorb a course placing emphasis on fundamental principles would find at these centres exceptional opportunities, both in his own specialization of metallurgy, and in the general intellectual life of a university town. The value of such background is accepted in the humanities, and it is difficult to see why this should not be equally true of the sciences. Last year, at Oxford, a new laboratory of the Department of Metallurgy was opened, and the following account gives a brief description of the laboratory as well as brief details of the research work

A NEW LABORATORY of the University Department of Metallurgy at Oxford was opened last year. The building is the first section of the new science area of the Keble Road triangle and was designed by Mr. George Buzuk, of Murray, Ward and Partners, London.

The laboratory has four floors. In the basement there is the main workshop, the mechanical testing room and the furnace room, which is at present devoted to high-temperature research work. There are also two X-ray rooms, one of which is being used for high-temperature X-ray work.

On the ground floor are rooms devoted to electron microscopy, powder metallurgy and precipitation hardening of alloys, high-temperature mechanical testing and X-ray diffractometry. The first floor contains the main teaching laboratories, the microscope room and the library. The study rooms of the staff are on the top floor, together with rooms for work on the constitution of alloys, the thermal analysis of high-melting alloys, zone melting and electron bombardment techniques, grain boundary precipitation and the freezing of alloys, and mechanical properties of metals and alloys.

The present staff consists of the Isaac Wolfson Professor (Dr. W. Hume-Rothery, O.B.E., F.R.S.), the George Kelley Reader (Dr. J. W. Christian), two lecturers (Dr. J. W. Martin and Dr. S. L. Altmann) and a graduate assistant (Dr. A. Hellawell). An independent honours degree course was established in 1956, while metallography remains a supplementary subject which may be read by

View of one of the teaching laboratories

Below is seen part of the lecture theatre

Photographs by courtesy of the 'Architect and Building News'

those whose main subject is in another branch of science.

The honours degree course in metallurgy is a four-year one. The metallurgical work, in which the emphasis is placed on fundamental principles rather than technological processes, is combined with the full Oxford course in inorganic and physical chemistry. Written and practical papers in these three subjects are taken after three years and constitute Part 1 of the final examination. The fourth year is spent on research in some topic related to metallurgical science, and the student submits a thesis and has an oral examination. The honours class is awarded on the combined results of Parts 1 and 2.

Individual research efforts

Professor W. Hume-Rothery. The structure and constitution of alloys of molybdenum with other transition metals are being examined, in the hope of throwing light on the general principles underlying the structure of transition metals and their alloys. The study of these alloys involves work at very high temperatures, and apparatus for this purpose is being developed. Similar work is being carried out on alloys of gold with elements of Groups IIB and IIIB of the Periodic Table, in order to see how they differ from the corresponding alloys of copper and silver.

A comprehensive experimental determination is being made of the freezing points and melting points of iron-rich alloys of iron with other transition elements, and of the effect of the latter on the A_4 transformation. Sixteen binary systems have already been investigated, and work is in progress on three binary and one ternary system. Other work includes experimental investigation on the structure of α-brasses, and of alloys of bismuth with rhodium and palladium.

Dr. J. W. Christian. The variation of the flow-stress of single and polycrystalline specimens of various metals with temperature and strain rate is being investigated in the temperature range 4–400°K. The results give information about the way in which dislocations overcome obstacles with the combined help of stress and thermal energy. In the b.c.c. metals, the main obstacle at low temperatures is the frictional resistance of the lattice, but in h.c.p. and f.c.c. structures, the obstacles arising from dislocation intersections are more significant. Related work includes a study of the crystallography of mechanical twinning in f.c.c. copper-aluminium alloys, and experiments on the mobilities of individual dislocations, using etch-pit techniques. The mechanism of bainitic-

type phase transformations, and especially the relation of the shape change to the theory of the crystallography of martensitic transformations, is also being studied.

Dr. J. W. Martin. A metallographic study of fracture characteristics of various materials is being made, as well as an investigation of the relationship between mechanical properties and microstructures in dispersion-hardened alloys.

The mode of fracture in tensile deformation over a wide range of temperature of commercially pure uranium is being studied. In the alpha-range, the role of dispersed non-metallic inclusions on the nucleation of fracture has been demonstrated. Electron-metallographic studies of fracture surfaces of temper-brittle steels are also being carried out, and transmission electron microscopy techniques of thin metal foils are being applied to an investigation of fatigue fracture in aluminium alloys.

Dispersion-hardening by internal oxidation is being studied in copper and nickel alloys, with particular emphasis on their elevated temperature mechanical properties. Powder metallurgical techniques are also being applied in this research. Dispersion-hardening of molybdenum alloys by the production of highly stable nitride precipitates is also carried out, and their high-temperature tensile, hardness and creep properties are being investigated. The effect of dispersed phases on the processes of recrystallization and grain growth is also being studied in aluminium copper alloys.

Dr. S. L. Altmann. A rather unusual feature of the department is the existence of a small theoretical group under the direction of Dr. S. L. Altmann, who is university lecturer in the theory of metals. The main interest of this group is the calculation of the band structure of metals as a step towards the understanding of their physical properties. Theoretical calculations in metals cannot often be relied on because even when the most sophisticated methods are utilized the physical model used is still very far from the real thing. One of the motives behind the work of the group is the need to develop methods that can easily be applied to a fairly large number of metals because, although the results for any single metal may not be very good, the general trends in moving along the periodic table are usually significant and useful.

In order to do this, very full use is being made of the university's electronic computer (a Ferranti Mercury), for which a programme is now almost ready that will provide a very detailed picture of the band structure of any hexagonal close-packed metal. The programme is entirely automatic; no changes except that of the atomic number, c/a ratios and the atomic potential field are required in changing the metal. Some half a dozen of them are expected to be computed this year, and work will soon commence on the cubic metals.

Dr. A. Hellawell. Experiments are being carried out which it is hoped will lead to a better understanding of freezing and, in particular, factors influencing solute distribution during solidification. In this connection we are (*a*) determining the effects of freezing rate, temperature gradient and concentration of the effective solid/liquid distribution coefficient; (*b*) determining the effect of solid/liquid interface structure on the preferred orientation in castings; and (*c*) studying the effects of solute concentration on the grain structure of castings.

Other experiments are being carried out to discover something about the mechanism of precipitation and growth occurring at grain boundaries.

Russian forging journal

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An experimental investigation of the heating of steel billets for forging and stamping in molten salts. A. D. AKIMENKO, M. YA. KUZELEV and A. A. SKVORTSOV. Pp. 40–42.
Mixtures of 30% $BaCl_2$ + 70% NaCl and 70% $BaCl_2$ + 30% NaCl were used in baths at 1,300°C. to heat billets to 1,200–1,250°C. The salt film produced on the billets is slight and creates no difficulties during forging. Heating time in a compartment furnace is two to three times longer than in a salt bath. Protective covers should be used to prevent heat losses by reduction. The mean value of the heat-transfer coefficient at bath temperatures of 1,200–1,350°C. was 400–500 kilocal./$m.^2 \cdot h. \cdot °C.$, accounting for the shorter heating time.

A recuperative compartment furnace for non-oxiding heating. G. F. DEGTEV and V. I. KARPENKO. Pp. 42–43.
Designed for heating components to temperatures between 600 and 1,250°C., to fire this furnace, air is preheated to 500°C. and natural gas to 400°C. in welded, scale-resistant steel recuperators, providing a furnace temperature of 1,300–1,350°C. with an air-consumption factor of 0·5–0·55. Specific consumption of comparison fuel is about 8%.

Modernization of a 9,000-tonne *press.* M. L. BORINSKII and V. S. STEPANOV. Pp. 44–46.

A die for manufacturing perforated sheet. D. L. TRABINOVICH. Pp. 46–47.

A stationary machine for cleaning metal after forging and rolling. P. D. NEPECHII and S. A. VOL'SKII. P. 48.

Radiographic examination of reactor pressure vessels

THE U.K. ATOMIC ENERGY AUTHORITY has just taken delivery of a mobile 4·3 million volt linear accelerator designed to make X-ray examinations of the pressure vessels of nuclear power stations during construction. Designed by Mullard Research Laboratories, the machine is the first completely mobile linear accelerator to be built anywhere in the world. It was developed under a contract placed by the Authority with Mullard Equipment Ltd. and will be used for the first time at the station being built for the Central Electricity Generating Board at Trawsfynnydd in Merionethshire.

The machine will enable the welds in the thick steel walls of the pressure vessel containing the reactor cores to be radiographed on site during the building of a nuclear power station, with the minimum of disturbance to the constructional work.

The accelerator has been engineered into a self-contained unit, which can be rotated about both horizontal and vertical axes for rapid, accurate alignment on to the specimen, and may be mounted on a tower, or suspended from suitable lifting tackle. For the first time on an equipment of this kind the entire vacuum and cooling systems have been incorporated in the accelerator unit, thus eliminating the problems of lengthy hose connections. The control cabin housing the ancillary electrical and control equipment is a transportable weatherproof structure of fibreglass which may be sited up to 250 ft. away from the accelerator.

Advantages of the linear accelerator

The linear accelerator is believed to be superior in this application to the cobalt 60 radio-isotope sources and conventional X-ray sets currently used for the purpose, since it enables radiographs of high definition to be obtained much faster, through the thicknesses of material encountered in this particular application. These advantages may well become even more marked when, as is probable, the thickness of the pressure vessel walls of future nuclear reactors is increased considerably beyond the present 3½ in.

The accelerator is very powerful for its size, producing at 4·3 MeV. a radiation intensity of over 600 röntgens a minute at a distance of 1 metre from the X-ray source. The focal spot size is less than 2 mm. in diameter. The time required to obtain a radiograph through 4 in. of steel with the accelerator 1 metre from the surface of the object can be as little as 4 sec.; an 8-in. thickness can be radiographed in 42 sec., and 12-in. in less than 9 min. To obtain an equivalent intensity from cobalt 60 would require a source of some 30,000 Curies; the physical size of such a source would be so great that the resulting penumbra effects would seriously reduce the definition of the radiograph. The Betatron, although capable of high penetration, requires lengthy exposures unless the machine is placed inconveniently close to the object.

The linear accelerator is able, because of its high intensity output and small focal spot size, to produce high-definition radiographs at considerable distances using relatively short exposures. It is thus possible to place the machine in the middle of the pressure vessel, and from this central point to radiograph the greater part of the vessel with the minimum of physical movement. At a distance of 30 ft., 10 ft. of weld can be examined at each exposure.

Technique

The travelling wave electron linear accelerator utilizes a high-power radio-frequency power generator to launch an electromagnetic wave into a specially constructed accelerating waveguide. The waveguide is circular and contains metallic iris discs which are spaced so as to increase the phase velocity of the wave from about 0·4 c (c = velocity of light) at the input to about 0·995 c at the output.

Electrons are injected into the waveguide, which is maintained under high vacuum, and 'surf-ride' on the electromagnetic wave, thus accelerating with it. At the output end they are travelling almost at the velocity of light and when they strike a metal target very hard X-rays are emitted; these are collimated to irradiate the area to be radiographed.

The radio-frequency power source is a high-power magnetron valve, which is pulsed from a modulator supplying electrical pulses of about 2 microseconds length at 50,000 volts and 100 amperes. Pulse repetition frequency is variable up to 500 pulses per second, therefore the equipment can be used for stroboscopic radiography of moving objects by relating the frequencies of the pulses to the periodicity of movement.

The present machine uses many of the standard units employed in the standard 4·3 MeV. accelerators which have been made by the company for a number of years for medical, industrial research and radiographic applications. Future U.K. sales of the equipment will be handled by Research and Control Instruments, who are the company's sole agents for radiographic equipment in Great Britain. Overseas enquiries should be addressed direct to Mullard Equipment Ltd.

Microplasticity in metals and alloys at low temperatures

P. FELTHAM, D.Sc., F.Inst.P.

Recent developments in research techniques, particularly the use of etch-pit metallography and transmission-electron micrography, have confirmed and clarified many theories and hypotheses on the mechanism of plasticity in metals. As a result of the observations on the behaviour of dislocations interest has become focused on some of their properties which still elude direct observation. On the process of dislocation intersection, important in work-hardening, on the formation and absorption of point defects by dislocations in creep and fatigue, and on many other characteristics of the mechanisms of plasticity on an atomic scale evidence is at present still largely inferential. It is shown in the present paper that studies of the microplasticity of metals and alloys, particularly the relaxation of stress, and transient creep at small plastic strains, can yield information on features of the dynamics of dislocations, occurring on an atomic scale. Special reference is made to the yield phenomenon in mild steel and in alpha-brasses, and to short-range order in the latter alloy, all of which were recently studied by means of creep and stress relaxation experiments at small plastic strains in the range 77–358°K.*

AT SUFFICIENTLY LOW temperatures, generally up to about $0{\cdot}3T_{melt}$ (°K.), many crystalline as well as some non-crystalline solids are known to exhibit a logarithmic type of creep if subjected to constant stresses, strain, ε, and time, t, being related by the equation

$$\varepsilon = s_c \log_{10}(1 + \nu t) \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

where, at any given temperature s_c and ν are time independent parameters which may, however, depend upon the stress and the temperature. Over ranges of t readily amenable to the study of the creep equation (1) can be written in the form

$$\varepsilon = s_c \log_{10} \nu t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

and then

$$s_c = d\varepsilon/d \log_{10} \nu t = d\varepsilon/d \log_{10} t \quad \ldots\ldots \quad (3)$$

In 1953 Mott derived equation (1) for metals and, in view of the generality of the derivation, it should be applicable to all crystalline solids in which dislocations are the source of plasticity. The assumptions on which his model is based are that crystallographic slip is a thermally activated process with a stress-dependent activation energy, and that intracrystalline stresses assisting in the activation diminish in the course of creep as a result of work-hardening. As a consequence the creep rate declines continuously, as may be seen on differentiating equation (1) with respect to time.

Similarly, a logarithmic type of stress relaxation is found in many materials maintained at a constant strain after plastic deformation at low temperatures. Kubát (1954), for example, observed it not only in metals but also in some plastics, rubber and paper. He ascribes it to the gradual decrease of internal stress gradients through elementary shears controlled by stress-dependent activation energies.

The equation relating the initial stress σ_0, the instantaneous stress σ and the time is

$$\sigma_0 - \sigma = s_r \log_{10}(1 + \nu t) \quad \ldots\ldots\ldots\ldots \quad (4)$$

and in practice this may again be written:

$$\sigma_0 - \sigma = s_r \log_{10} \nu t \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

with

$$s_r = -d\sigma/d \log_{10} t \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

The conditions under which logarithmic creep and stress relaxation occur, as well as the explanations advanced to account for them, suggest that

*The author, of the Department of Metallurgy, The University, Leeds, gave this lecture before the British Society of Rheology at the University of Reading last April.

both phenomena are related. In the work here described an attempt was made to examine whether in fact such a relation could be established theoretically and, if so, in how far it could be supported by creep and stress relaxation measurements on some metals and alloys. It was also hoped to obtain a deeper insight into the specific rate-determining mechanism operative in metals and, probably, in other crystalline solids as well.

The experimental work was carried out on polycrystalline specimens which had been well annealed *in vacuo* at high temperatures prior to use, and the plastic strains were in all cases confined to less than about 3%. At such comparatively small strains the coefficient of work-hardening $\chi \equiv d\sigma/d\varepsilon$ is found to be approximately constant, and this was expected to be of assistance in any correlation of corresponding parameters of the creep and relaxation equations.

Experimental

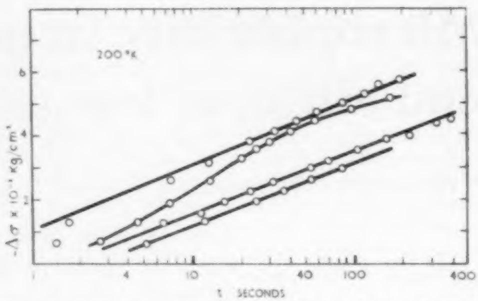
In the experiments metal rods were extended in a Hounsfield leaf-spring type of 'Tensometer'; the relaxation was determined by observing the mercury column serving as stress indicator, while, in creep experiments, the strain required to keep the column immobile after the application of a small plastic deformation was recorded. The specimens were mounted in a tubular cryostat, and submerged in liquid nitrogen, solid carbon dioxide in alcohol, melting ice or silicone oil heated to 85°C. Some tests were carried out at room temperature, without the cryostat. Typical stress relaxation curves for annealed iron containing 0·11% C (wt.), obtained at 200°K., are shown in fig. 1. Irregularities in the curves were observed at strains within about 0·03% of the yield point, indicated by the broken curve in fig. 1; at higher strains the results were reproducible. Similar effects were also observed in the relaxation of copper and alpha-brasses. Detailed descriptions of the experimental procedure and of the results obtained with brasses (Feltham, 1961a, 1961b), and with iron (Feltham, 1961c), have been published. The strain-time curves obtained in creep are similar to the relaxation curves (Feltham, 1961b).

Theoretical

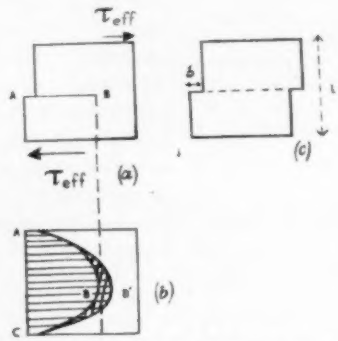
Relation between creep and relaxation

Now, in a work-hardening material the rate of change of the applied stress with time, at any given temperature, may be expressed in terms of the relaxation at constant strain and the variation due to work-hardening:

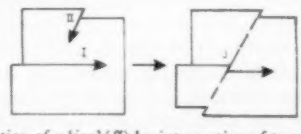
$$\frac{d\sigma}{dt} = \frac{\delta\sigma}{\delta t} + \frac{\delta\sigma}{\delta\varepsilon}\,\frac{d\varepsilon}{dt} \quad \ldots\ldots\ldots (7)$$



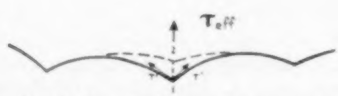
1 *Stress relaxation in iron containing 0·1% C at 200°K.*



2 *Passage of an edge dislocation through a crystal:* **a** *and* **b** *dislocation stuck at B;* **c** *dislocation passed through the entire crystal*



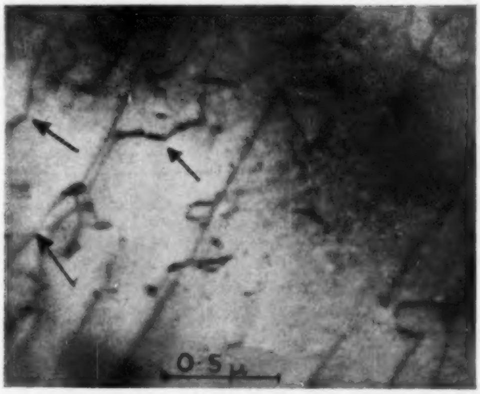
3 *Formation of a 'jog' (J) by intersection of two dislocations*



4 *Migration of a 'jogged' dislocation from* 1 *to* 2. *T' is the line tension of the dislocation containing the jog*

which, for stress relaxation at constant strain reduces to:

$$\frac{d\sigma}{dt} = \frac{\delta\sigma}{\delta t}; \quad \frac{d\varepsilon}{dt} = 0 \quad \ldots\ldots\ldots (8)$$



5 *Dislocations in a thin film of oxygen-free high-conductivity copper. Annealed* in vacuo *for 2 h. at 850°C. followed by about 2% reduction by rolling. Arrows indicate loops as shown in* **4** *(electron micrograph by R. Sinclair)*

while for creep under constant stress:

$$\frac{\delta\sigma}{\delta t} = -\chi\frac{d\varepsilon}{dt}; \qquad \frac{d\sigma}{dt} = 0 \quad \ldots . \quad (9)$$

χ is the coefficient of work-hardening, which we shall assume to be independent of time and strain in the (linear) part of the stress-strain curve used, so that:

$$\frac{\delta\sigma}{\delta\varepsilon} = \frac{d\sigma}{d\varepsilon} = \chi = \text{constant} \quad \ldots . \quad (10)$$

On substituting for $\delta\sigma/\delta t$ from equation (8) into equation (9), and multiplying both sides by t, one obtains:

$$d\sigma/d\log_{10}t = -\chi\, d\varepsilon/d\log_{10}t \quad \ldots\ldots\ldots \quad (11)$$

so that, with a constant value of χ, logarithmic creep and logarithmic stress relaxation are in fact conjugates, with (equation (3), (6) and (11)):

$$s_r/s_c = \chi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

Measured values of χ in alpha brass containing 35% of zinc gave:

$$40 < G/\chi < 50 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

where G is the shear modulus and, as can be seen from table 1, this is in good agreement with $G/(s_r/s_c)$, as required by equation (12).

Dislocation model of the stress-relaxation process

In the model which we now propose to discuss we shall assume that in crystalline solids the relaxation results from a limited continuation of slip if the stress is maintained on the specimen after a preceding small amount of plastic deformation. The residual glide arises from the movement of dislocations to positions of lower potential energy, which can take place without an increase of the applied stress. At constant strain these 'microscopic' shears then facilitate a relaxation of stress.

A diagrammatic representation of the shear displacement occurring in a small crystal cube (which may represent a grain in a polycrystal) is shown in fig. 2. An edge dislocation has moved from the crystal surface at A along a glide plane into the interior to B. The dislocation line bounds the area in the glide plane over which slip has taken place, *i.e.* ABC in the plan projection of the crystal. The strain increases as the dislocation moves further into the crystal; if it moves right through then, as is apparent from the sketch on the right in fig. 2, the shear strain is $\mathbf{b}/L$, where $\mathbf{b}$ is the Burgers vector of the dislocation and L the length of side of the crystal cube. The strain at any stage of advance of the dislocation into the crystal will be proportional to the slipped area swept out by it, and migration from the position ABC to $AB'C$ will induce a strain equal to $(\mathbf{b}/L)\ (AB'CB/L^2)$, where $AB'CB$ is the crescent shaped area, and L^2 the area of the slip plane of the crystal. We see, therefore, that small displacements of dislocations can lead to creep as well as to a redistribution of internal stresses, resulting in relaxation. We now have to consider why the dislocations do not traverse the whole crystal once they are set in motion by the action of a shear stress, *i.e.* why the dislocations are 'hung up' inside the grains.

Now, the requirement of continuity of the material in plastic deformation necessitates the simultaneous operation of slip on more than one slip system, so that dislocations moving on system I for example (fig. 3) will be intersected by others gliding in systems such as II. As a consequence the dislocations will acquire Z-shaped imperfec-

TABLE 1 *Creep and stress relaxation data for 65/35 alpha-brass polycrystals*

°K.	77	200	273	289	299
Tensile yield stress $\delta_y \times 10^{-3}$ kg./cm.²	14·3	10·0	—	8·0	—
Shear modulus $G \times 10^{-5}$ kg./cm.²	4·50	4·35	4·21	4·20	4·18
s_r kg./cm.²	26	19	12	11	10
$s_c \times 10^4$	29	23	15	12	11
$(s_c/s_r) \times 10^4$ cm.²/kg.	1·1	1·2	1·2	1·1	1·1
$G/(s_r/s_c)$	50	53	52	46	46

tions, shown at *J* in fig. 3, where the slip zone is stepped up (or down) by one Burgers vector. A complex lattice imperfection is formed at such 'jogs,' and will exercise a frictional drag if the dislocation moves under stress. This 'ploughing up' of the crystal lattice by jogs occurs more readily at high than at low temperatures; the activation energies associated with the process would be expected to be equal to a significant fraction of the energy for vacancy migration (Maddin and Cottrell, 1955; Feltham, 1961b).

Logarithmic stress relaxation

Fig. 4 shows part of a dislocation hung up at jogs, *i.e.* at points such as 1. The line tension T of the dislocation (bowed out under an effective shear stress τ_{eff}) tends to move the jog to a position of lower internal stress, 2, in a manner analogous to the movement of a stone by the rubber arms of a catapult. If the energy barrier to the movement of a jog is Q it will be reduced by an amount proportional to τ_{eff}. The velocity of the jog along 1–2 will be:

$$dx/dt = \nu_0 \mathbf{b} \exp\{(-Q/\boldsymbol{k}T)[1-(\tau_{eff}/\tau_j)]\} \quad \ldots(14)$$

where x is the distance along 1–2 measured from 1, t the time, ν_0 an atomic frequency of the order of 10^{12}/second, $\mathbf{b}$ the Burgers vector of the jog, $\boldsymbol{k}$ is Boltzmann's constant, T the temperature in °K., and $\tau_j(T)$ a measure of the strength of locking of the dislocation containing the jog. The ratio of the shear stresses may formally be replaced by that of corresponding tensile stresses, so that:

$$\tau_{eff}/\tau_j = \sigma_{eff}/\sigma_j \quad \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

As may be seen from equation (15) and the fact that the value of the bracketed 'activation' term is zero if

$$\sigma_{eff} = \sigma_j \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

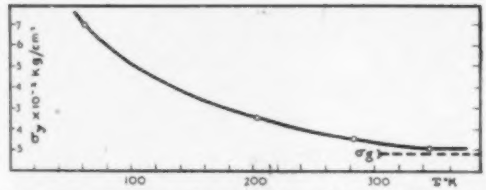
σ_j is numerically equal to the effective stress at which the jog would move with the velocity $\nu_0\mathbf{b}$ without the aid of thermal activation. At very low temperatures equation (16) must be approximated closely, as is clear from equations (14) and (15).

We shall assume that at 1 (fig. 4) the effective stress is greater than at 2, in which position the jog will remain at rest virtually indefinitely, σ_{eff}/σ_j being comparatively small. As an approximation we shall take the stress gradient between 1 and 2 to be constant, so that, with x measured in the direction of the movement of the defect:

$$d\sigma_{eff}/dx = -K = \text{constant} \quad \ldots\ldots\ldots (17)$$

On multiplying the right- and left-hand sides of equations (14) and (17) respectively, also using equation (15), integrating the resulting differential equation and rearranging, we obtain:

$$\exp(-\sigma_{eff}Q/\sigma_j\boldsymbol{k}T) = (KQ\nu_0\mathbf{b}/\sigma_j\boldsymbol{k}T)(t+\nu^{-1}) \quad ..(18)$$



6 *Temperature-dependence of the upper yield point in annealed polycrystalline iron containing* 0·1% *wt. C. The temperature-independent part of the yield stress is indicated by the horizontal broken line*

where ν is a constant of integration. At any given temperature therefore:

$$d\sigma_{eff}/d\log_{10}(1+\nu t) = -2{\cdot}3\,\sigma_j\boldsymbol{k}T/Q \quad \ldots\ldots (19)$$

Further, if we assume that:

$$\sigma_{eff} = \sigma - \sigma_i \quad \ldots\ldots\ldots\ldots\ldots\ldots (20)$$

where σ_i is an 'elastic' internal stress opposing the applied stress σ, and that the variation of σ_i with time is negligible compared with that of σ, then equation (19) yields the logarithmic law of stress relaxation (equation (4)) with:

$$s_r = -2{\cdot}3\,\sigma_j\boldsymbol{k}T/Q \quad \ldots\ldots\ldots\ldots\ldots (21)$$

It appears from the work on stress relaxation in copper, brasses (Feltham, 1961a, 1961b) and iron containing 0·1% C (Feltham, 1961c), that in the experiments close to the yield point, $\sigma_y(T)$, the stress $\sigma_j(T)$ is given by:

$$\sigma_j = \sigma_y - \sigma_g \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

where σ_g is the temperature-independent part of σ_y, indicated in fig. 6 by the horizontal broken line.

Conclusions

Values of the activation energies Q deduced by means of equation (21) for the metals and alloys mentioned lie between ¼ and ½ eV. (5–10 kcal./gram atom), and are thus of the right order of magnitude if the migration of elementary jogs is energetically akin to the movement of a 'small' vacancy. The minimum in the Q versus Zn% graph in alpha-brasses, found at compositions close to Cu_3Zn, can also be explained satisfactorily in terms of short-range order localized near jogs (Feltham, 1961b). It may therefore be concluded that the utilization of 'microplasticity,' *i.e.* creep and stress relaxation at small strains at low temperatures, can yield data on the mechanism of deformation and on special features of the structure of metals and alloys occurring on an atomic scale.

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Isothermal heat treatment

ALAN D. HOPKINS, M.Sc., A.I.M.

It is shown in this article how the theoretical studies of Davenport and Bain have profoundly influenced the practice of heat treatment and it is suggested that their influence may one day extend into the field of mechanical working*

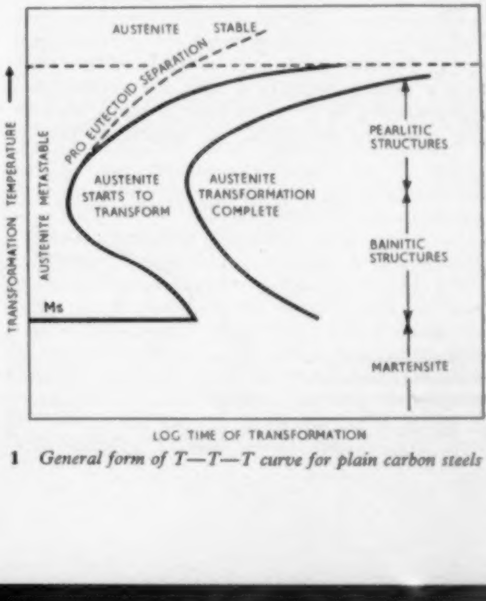
PROBABLY THE MOST IMPORTANT development in heat-treatment practice during the past 30 years is the discovery and utilization of the data contained in the S, IT, or T—T—T curves as they have come to be called. Until 1930, when Davenport and Bain's[1] paper was published, most investigations into the hardening of steel were carried out using what would now be called continuous cooling techniques. Much information concerning the depression of the critical points by the addition of alloying elements and/or by increase in the cooling rates had been accumulated, but it was of little direct industrial application.

The technique which Davenport and Bain applied was so simple and has become so well known that it does not require lengthy description. In brief, small specimens are cooled rapidly from the austenitic state to a temperature below the A_1. The progress of the transformation at this constant temperature is followed by observing the metallographic, volume or magnetic changes which take place during the transformation of the metastable austenite to pearlite, bainite or martensite. In order to reach the transformation as rapidly as possible, it is customary to quench the austenitized metal into a liquid salt or metal bath.

The general features of the time—temperature—transformation curves for plain carbon steels are shown in fig. 1. With increasing amounts of carbon up to the eutectoid composition the T—T—T curves are moved to the right, *i.e.* there is a longer induction period before the transformation of austenite begins and the M_s and M_f temperatures at which transformation of martensite begins and ends are depressed. Although data relating to the martensite reaction is customarily included in the isothermal transformation diagram, it must be remembered that martensite formation does not take place at constant temperature. A temperature gradient must exist in austenite for martensite to form on cooling below the M_s temperature. In hyper-eutectoid steels the depression of the M_s and M_f temperatures increases with carbon content, but the induction period for transformation to pearlitic products is reduced. The induction period for transformation to bainite (below the 'nose' of the curve) increases.

The addition of alloying elements to steel has the following effects. All elements except cobalt cause the T—T—T curves to be shifted to the right, *i.e.* the transformation takes longer to begin and once it has started takes longer to complete with increase in alloying element. The bainitic region is in general less affected in this way, but, with large amounts of alloying element, the bainite curve separates itself from the upper part, so that for alloy steels we can present fig. 2 as an archetype. M_s temperatures are only slightly depressed by the addition of alloy elements.

*Article based by the author on his lecture given at the Birmingham College of Advanced Technology last January in the series 'Modern developments in the theory and practice of steel heat treatment.' The author is with the Department of Metallurgy of the college. Articles based on other lectures in the series will be published in future issues of METAL TREATMENT.



1 *General form of T—T—T curve for plain carbon steels*

In the 30 years that have intervened since the pioneer American work many developments have been made. Transformation diagrams have been determined for many steels and the most important collections have been published by the Iron and Steel Institute,[2] the United States Steel Co.[3] and a German organization.[4] In addition our understanding of the theory of T—T—T curves was greatly widened by the work of Mehl and his school. An adequate summary of their application of nucleation and growth theory may be found in the literature.[5, 6] A direct effect of these studies was the recognition of the importance of austenite grain size and austenite heterogeneity on the course of transformation. Hardenability studies were greatly facilitated by the existence of this body of theory and practice and, in short, scientific heat treatment began with Davenport and Bain's paper.

To summarize, the studies of the transformation characteristics of steels have shown that all steels, whether plain carbon or alloy, behave essentially in a similar way. Three modes of transformation can be recognized: (1) Transformation at relatively high temperatures below the equilibrium transformation temperature to yield pearlite; (2) transformation to bainite below the nose of the curve; and (3) transformation to martensite at temperatures below the M_s point.

The development of each of these structures forms the basis of an industrial heat-treatment process in isothermal annealing, austempering and martempering respectively. Each of these processes will be discussed in detail. The cooling cycles are shown superimposed on a T—T—T curve in fig. 3.

Isothermal annealing

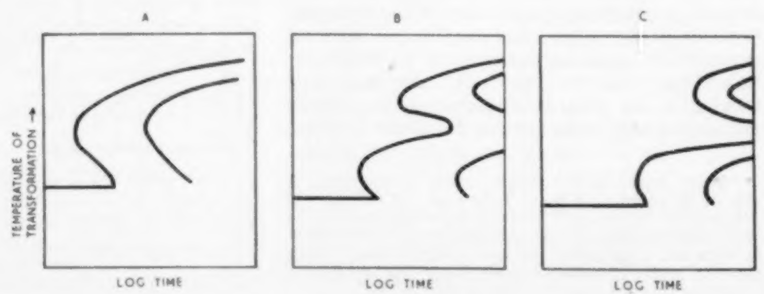
To obtain a soft structure, annealing or normalizing can be carried out on plain carbon steels. The development of a lamellar pearlitic structure gives favourable machinability properties to hypo-eutectoid steels. For alloy steels which are air or oil hardening such a process requires a very low cooling rate and tempering of the martensitic or partly martensitic structure developed on natural cooling is generally applied, although isothermal annealing may be helpful.

Eutectoid or hyper-eutectoid steels generally require a spheroidized structure as opposed to the lamellar structure for machinability. This structure may, of course, be developed by prolonged sub-critical annealing. For example, silver steel will require 1 h./in. of section at 650°C., whereas 18 : 4 : 1 requires heating at 870–890°C. for 4 h./in. of section followed by furnace cooling. Especially with high-alloy steels the quoted times may be insufficient to bring about spheroidization and, although softening may occur, the material may not have optimum machinability. The softening of such tool steels for machining using orthodox annealing methods is therefore a lengthy process and, unless adequate precautions are taken such as packing the tools in cast-iron borings, decarburization will result. For many such materials isothermal annealing is advantageous in that it will give a more uniform structure, without excessive decarburization, in a shorter time (*e.g.* file blanks). Typical conditions of isothermal annealing are given in table 1.

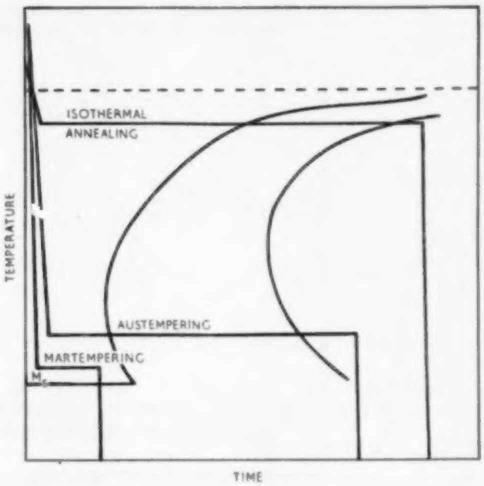
TABLE 1 *Recommended conditions for isothermal annealing*

	Austenitize	Transform
	min. °C.	h. °C.
Silver steel	15 at 800	3 at 680
10% W hot die steel	15 at 880	1½ at 650
High carbon/high chrome ..	15 at 880	3 at 710
18 : 4 : 1 high-speed steel ..	15 at 900	1 at 750

The above conditions specify a short time of austenitizing at a relatively low temperature. Payson[7] recommends that the higher the austenitizing temperature the greater the tendency for a lamellar structure to be formed. He states that, to develop the softest condition, austenitizing should be carried out at not greater than 40°C. above the critical range and transformation at 40°C. below the critical. Cooling from the austenitizing temperature to the transformation temperature



2 *Development of form of T—T—T curve with increasing alloy content:*
A Carbon steel
B 100-ton steel
C Alloy tool steel



3 *Isothermal heat treatments*

must be rapid. Rapid cooling is permissible after transformation is complete. Preheating of 0·7–0·9% C and low-alloy steels for several hours at 10°C. below the critical minimizes the formation of lamellar pearlite. The development of the spheroidal structure in hypo-eutectoid steels is inhibited by aluminium deoxidation.[8] In general, the spheroidite structure is promoted by austenite inhomogeneity. Of course, the spheroidal structure is not always desirable in hypo-eutectoid steels, but for cold heading, turning and boring operations it is generally considered preferable to the lamellar product.

In practice, isothermal annealing is best carried out by using salt baths, but muffle-furnace practice can be modified to give acceptable results under certain conditions. By cooling from the austenitizing temperature to a subcritical temperature, holding for the necessary period and then cooling, a satisfactory cyclic anneal can be produced. However, the thermal lag of a loaded muffle furnace might possibly prevent this attainment of the ideal conditions of a short austenitizing period, followed by rapid cooling to the annealing temperature. Furthermore, the salt bath will prevent decarburization—an extremely pertinent advantage for a hardened and finished tool which must be softened for machining without destroying the surface, *e.g.* nail-gripper dies made from carbon-chromium steel.

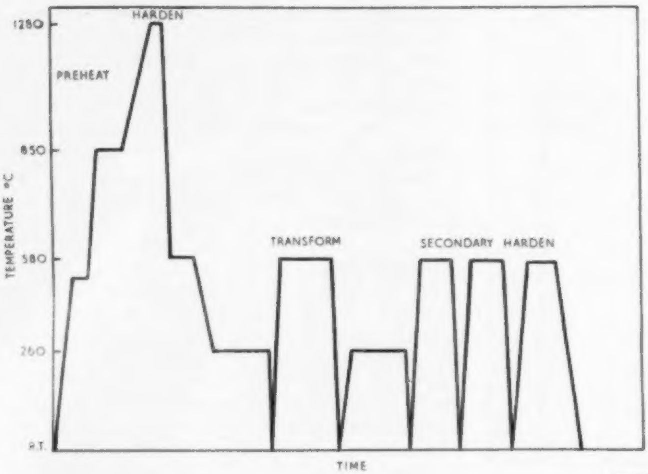
In short, isothermal annealing may be more rapid than the orthodox furnace annealing process and, even if it is unpractical to carry out the process under the ideal conditions using salt baths, the application of the principles of the process to cyclic annealing may be economically and technically advantageous. For this purpose the published T—T—T curves may not be helpful, since austenite inhomogeneity is not generally fostered under the conditions of their determination. Generally the possibility of spherodite formation is ignored in published T—T—T curves. However, they give a guide to temperatures and times of transformation.

Austempering

For all steels, the lower the temperature of transformation below equilibrium the harder the structure produced. Within the range between the M_s temperature and the nose of the T—T—T curve, the hardness of bainite obtained at a particular temperature of transformation is roughly equal to that of martensite tempered at the same temperature. At a given hardness the bainitic structure is more ductile and tougher than tempered martensite. The endurance limit of austempered springs is the same as that of hardened and tempered springs.[9] In this country the process is generally confined to carbon steels containing 0·6–1% carbon austempered at 250–330°C. for ¼–1 h. in a nitrate-nitrite salt bath depending on the hardness required. Certain users of the process find that austempered springs have a lower elastic limit than tempered martensite of the same hardness, but others find no difference. When carbon steels are used, the process is restricted to sections of less than 0·125 in.

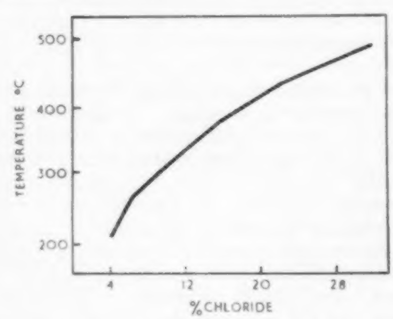
It would appear that the use of alloy steels of higher hardenability would remove this limitation of small section and enable superior properties to be realized with less distortion than is obtained by oil quenching followed by reheating for tempering. Here again a difference of opinion exists, for it appears that low-carbon alloy bainites are more brittle than tempered martensite unless the bainitic structure is subsequently tempered. It may be that, while alloy bainites are not inherently brittle, incomplete transformation to bainite is obtained, and on cooling to room temperature a mixture of bainite and untempered martensite is found. Additionally, austempering temperatures are within the range where '350° embrittlement' occurs and this may contribute to erratic results.

Probably the field of application of austempering is inevitably restricted to carbon steel, since either long transformation times or the need for subsequent tempering treatment would make the process too long and too costly, bearing in mind that two or three times the duration of treatment prescribed by the diagram should be allowed. However, the list of profitable applications of austempering includes small springs and clips,



4 LEFT *Full cycle for bainitic hardening of 18 : 4 : 1 high-speed steel*

5 BELOW *Solubility of KCl-NaCl heat-treatment salt in nitrate-nitrite salt*



typewriter parts and hand tools. In this last group there is probably still scope for many more applications.

Generally, although low-carbon alloy steels have not provided amenable to austempering, an austempering process has been applied to 18 : 4 : 1, 6 : 6 and 5% cobalt high-speed steels[10] to produce tougher tools. The treatment is lengthy and consists of hardening at 1,260–1,300°C. for the appropriate time followed by quenching at 260°C. and holding for 4 h. followed either by the customary double secondary hardening or by reheating to 560°C. for 4 h. followed by a further 4-h. treatment at 260°C. with subsequent double secondary hardening. The complete heating cycle is shown in fig. 4. For 12% cobalt high-speed steel the austempering temperature is 205°C.

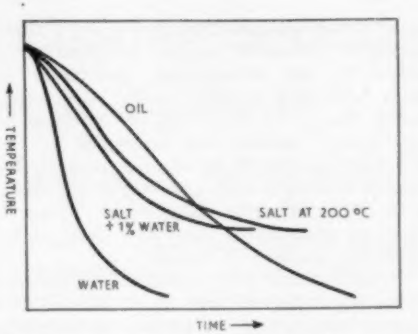
The above treatments are, of course, expensive due to the increased number of processes and their duration. In addition to increased toughness, improved tool lives are claimed, but whether on balance the process is worth while is doubtful, and the author is not aware that it is used in the United Kingdom. It may be concluded that austempering is largely restricted to high-carbon steel components, inevitably of thin section where enhanced properties can be obtained with less distortion.

In practice, austenitizing is usually carried out in a muffle furnace having a protective atmosphere and the transformation process in a nitrate-nitrite salt bath at 250–350°C. The times of treatment at a particular temperature can be roughly determined by reference to the appropriate T—T—T curve, but caution is necessary to take into account the possible effects of grain size and tramp elements in prolonging the transformation times by a factor of two or even three. Deficiencies in hardenability may be overcome by increasing the austenitic grain size through an increase in austenitizing temperature.

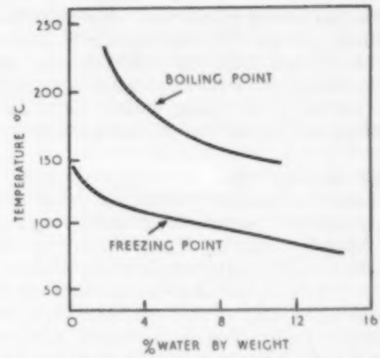
Martempering

The problem of minimizing distortion is probably the most pressing and persistent of all that face the metallurgist. Of all the incidental advantages that an understanding of T—T—T curves has brought, the introduction of the martempering process has probably been the most beneficial. The process consists of heating to the hardening temperature and quenching into a salt bath held at a temperature just above the M_s temperature until the temperature throughout the component has been equalized. The formation of martensite takes place on subsequent air cooling at the same time in all parts of the component. The process is simple and only the following conditions are important:

1. The austenitizing operation must be carried out correctly.



6 *Diagram of cooling rates in various quenching media*



7 *Effect of water on properties of nitrate-nitrite salt (Mehrkam)*

2. The rate of cooling to the martempering temperature must be sufficiently rapid to prevent transformation during cooling.

3. The duration of holding at the martempering temperature must be as short as consistent with the equalization of the temperature of the component.

The adoption of martempering for heat treatment is usually successful if the component can be satisfactorily hardened by oil quenching. Although the M_s temperature of steels varies with composition, the most important factor affecting M_s temperature is the carbon content. The M_s temperature of most En steels is 350–250°C. except for En 42 and 44 spring steels and En 31 ball-bearing steel, which have M_s temperatures of 200°C. This is borne out by inspection of the empirical formulae which have been established. For instance, Nehrenberg's[11] formula:

M_s (°C.) = 500 −300 C −33 Mn −22 Cr −17 Ni −11 Si −11 Mo.

It should be emphasized that this formula will give incorrect results for higher-alloy steels, *e.g.* tool steels, where incomplete solution of alloy carbides occurs.

In practice, a quenching temperature of 250°C. is satisfactory for most En steels, both heat treating and case hardening, although for low-alloy steels such as En 18, it may be necessary to reduce the martempering temperature to 200–220°C. to avoid transformation to softer products above the nose of the curve. Distortion occurring on martempering at 200–250°C. may be overcome by transforming at 300°C. particularly with tool steels such as 2% carbon 12% chromium, which have a long induction period at these temperatures. It must be appreciated that the initial rate of cooling in the salt bath may be greater than in oil quenching where the production of the vapour cushion reduces the thermal shock.

Martempering is carried out either in a hot oil bath at a maximum temperature of 230°C. or in nitrate-nitrite salt bath. The oil bath, on account of its instability and inflammability, is less favoured than the more costly salt bath, which is simple, safer and can be operated at higher temperatures. Austenitizing can be done in muffle furnaces or in a chloride salt bath. Contamination of the martempering salt by chlorides will lead to eventual reduction in quenching power. The solubility of chloride heat-treatment salt in a nitrate-nitrite salt is shown in fig. 5. Consequently a feature of such installations is a salt separating chamber maintained at a lower temperature in which a proportion of the chlorides are rejected from the solution.

In German practice, continuous separators are not fitted, but periodically the salt is baled out into a conical mould when the denser chloride particles settle to the bottom of the cone and can be broken away from the remainder. The addition of 0·5% sodium chromate is stated[13] to overcome the chloride contamination and to restore quenching power.

The quenching power of a nitrite-nitrate salt bath is equivalent to that obtained in a well-agitated oil quench.[12] An increase in quenching rate can be achieved by the addition of 1% water to the salt bath. These effects are illustrated in fig. 6. This procedure may sound dangerous, but is accomplished quite safely by directing a metered fine jet on to the agitator shaft of the bath. The process involving the addition of water is regularly in use in this country to reduce distortion of water hardening chrome-vanadium tool steel parts. Martempering at 200°C. gives a hardness of Rc 61–62. Analytical control of the water content of the salt can be achieved by measurement of the depression of freezing point of the salt as illustrated in fig. 7.

Many examples could be quoted of the regular use of martempering to reduce distortion and give

uniform hardening conditions. For example, the hardening of En 35 case-hardened automobile gears, tools and dies, and roller-bearing cases.[14] The technique is of proven reliability and there must certainly be many more heat-treatment operations that would benefit from its introduction.

Recent developments

The modified Sulfinuz process. The I.C.I. Sulfinuz process involves treatment of steels or cast iron in a cyanide nitriding bath containing sodium sulphide at 570°C. for periods of up to 2 h. The results of service and laboratory tests, combined with the experience of users in diversified fields of application of the Sulfinuz process, have shown that the high hardness normally obtained by case-hardened components is not necessary to prevent scuffing and give good wear resistance, particularly under conditions where lubrication is difficult.

However, certain moving parts in contact may require high strength which would be lost by Sulfinuz treatment at a relatively high temperature. In an attempt to provide the advantages of the scuffing resistance of Sulfinuz treatment at the same time as developing a reasonable hardness, a modified Sulfinuz process that has been investigated involves austenitizing at the appropriate temperature and quenching into a Sulfinuz bath at 570°C. for 2 h. followed by air cooling.

By the use of such steels as En 17 (035 C $1\frac{1}{2}$ Mn 0·4 Mo) or carburized En 34 ($1\frac{3}{4}$ Ni 0·25 Mo), which have a long induction period at 570°C., austenite remains substantially untransformed to harden on subsequent air cooling. For En 17, a surface hardness of Rc 38–40 resulted from this type of treatment. The fatigue strength (Avery plane bend test) was $\pm 37 \cdot 5$ ton/sq. in.—substantially higher than the fatigue limit of En 17 quenched and tempered at 570°C. Amsler Wear tests carried out at a load equivalent to 21·5 ton/sq. in. showed that, in spite of the lower hardness (Rc 42 as compared with Rc 53), the Sulfinuz-treated test pieces showed no scuffing after 10^6 revolutions in the test, whereas the quenched specimens of En 17 and En 34 had scuffed badly after only 10^4 revolutions.

The results of these tests indicate that the process is promising and suggest that this type of treatment might be of wide application, particularly for gears. A further important question that arises is whether the engineering maxim that hard surfaces are required for wear resistance does not require reappraisal.

The 'Ausforming' process. The modified Sulfinuz process is an illustration of utilizing the prolonged period of metastability of austenite in certain temperature ranges to carry out surface treatments. In the 'Ausforming' process (a Ford trade mark) steels having a similar type of T—T—T curve are plastically deformed in the temperature range 430–570°C. and subsequently quenched. Using steels containing 0·48% C, 3% Cr, 1·5% Ni, 0·75% Mn, 0·5% Mo, 1·5% Si, Schmatz, Shyne and Zackay[17] showed that increasing the amount of reduction brought about an increase in U.T.S. and yield strength with a corresponding reduction in ductility. However, strengths of 150 ton/sq. in. could be obtained in these materials, while still retaining a measure of ductility.

Other workers[18] have confirmed the increase in strength obtained by working at sub-critical temperatures and have noted an increase in toughness. The increased strength is ascribed to the production of finer martensite plates in deformed austenite. The rate of transformation of deformed austenite is greater[19] than the undeformed material. One is tempted to speculate whether such a process could be adopted on a commercial scale. It is conceivable that it could be used for the production of small forgings followed by direct quenching or perhaps in the drawing of higher-strength wire when the coil and die could be submerged in a salt bath.

In conclusion, it has been shown how the theoretical studies of Davenport and Bain have profoundly influenced the practice of heat treatment and it is suggested that their influence may one day extend into the field of mechanical working.

Acknowledgments

The author would like to thank his former colleagues at I.C.I. Heat Treatment Centre, Oldbury, for their co-operation in supplying information concerning salt-bath processes, especially the modified Sulfinuz treatment which they are currently developing.

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Estimating critical ranges in heat treatment of steels

Formulas are proposed for calculating the upper and lower critical temperatures from the chemical compositions of medium carbon and low-alloy steels. Mean deviations of measured values from calculated values are between 5% and 6%. (N8, 2–60, CN AY.) This article is reproduced from Metal Progress, *April,* 1961. *The author, R. A. Grange, is Senior Scientist, Edgar C. Bain Laboratory for Fundamental Research, United States Steel Corp., Monroeville, Pa., U.S.A.*

WHEN HEAT TREATING STEEL, it is often helpful and sometimes essential to know the upper and lower critical temperatures to within a few degrees. Since it is somewhat difficult to measure these two temperatures in a particular steel, the metallurgist usually has recourse to tabulations of Ac_1 and Ac_3 temperatures which appear in various handbooks. However, there is a drawback to this procedure. Though such tables include values representative of each standard type of steel, they do not reveal the variation to be expected from differences in composition among individual heats of each grade. And it is also helpful to be able to estimate reliably the lower and the upper critical temperatures from the composition of *any* heat of steel, whether it is a standard type or not.

Because these temperatures depend primarily upon chemical composition of the steel, we have, over a period of years, determined the upper and the lower limits of austenite formation for a great number of heats representing over 50 different compositions. After collecting and statistically analysing these data to reveal the quantitative effect of each of the principal alloying elements, we have been able to combine the individual effects in the form of empirical formulas.

Terminology

Before discussing these formulas, we should consider the question of terminology. When the lower and upper limits of austenite formation in hypoeutectoid steels are measured by continuously heating at some specified rate, they are called 'Ac_1' and 'Ac_3,' respectively. In either instance, the temperature which is determined varies with the rate of heating. It is lower with slower heating rate, the closest approach to equilibrium being attained when the steel is heated at the slowest possible rate.

A less-tedious method, which yields essentially the same value, consists of holding specimens at each of a series of constant temperatures for varying periods of time up to several hours (or at least until doubling the holding time causes no appreciable change in the amount of austenite formed), and then quenching to room temperature. The lower and upper limits of austenite formation determined by this isothermal technique have usually been designated 'Ae_1' and 'Ae_3,' subscripts '1' and '3' referring to the A_1 and A_3 lines of the iron-carbon phase diagram.

However, there are ambiguities. In steel which contains three or more elements, the A_1 can become a three-phase field. Furthermore the 'e' implies true equilibrium conditions which are rarely if ever attained in steel of commercial purity. For these reasons, we propose to use the symbols 'A_s' and 'A_f' in this article. In accord with the well-established use of 'M_s' and 'M_f' (to denote the temperature range of martensite formation), 'A_s' is defined as the temperature at which a barely detectable amount of austenite forms during prolonged holding at constant temperature and 'A_f' is the temperature at which the last trace of *ferrite* transforms to austenite on prolonged isothermal holding.* Practically speaking, therefore, A_s constitutes a 'ceiling' for tempering and A_f a 'floor' for austenitizing hypoeutectoid steel.

Calculating the formula

From data representing the effects of manganese, silicon, nickel, chromium and molybdenum, we developed formulas for estimating the upper and lower critical temperatures. To do this, we first plotted, for each element, the percentage amounts of alloys against the resulting A_s and A_f temperatures. The curves which we obtained showed that both temperatures changed a given amount with each additional percentage point of alloying element. (For example, the A_s temperature dropped about 25°F. with each per cent. of manganese; therefore, the formula for calculating the upper critical temperature includes the factor, '$-25 \times$ % Mn.')

Of course, this method requires a straight-line relationship, and the quantitative effect of each of

*It would be desirable from the fundamental standpoint to define A_f as the minimum temperature for total austenite formation. However, this leads to the experimental difficulty of measuring the exact temperature at which the last trace of carbide dissolves in austenite, a test that is difficult, if not impossible, to do. Thus, A_f as defined above has little or no significance in respect to the heat treatment of hypereutectoid steels.

these elements on either A_s or A_f is usually not directly proportional to its weight percentage. However, over a limited range for each element, only a small error results from assuming direct proportionality. The combined effect of phosphorus, sulphur and residual elements is assumed to be small; hence it can be neglected without appreciable error. Furthermore, molybdenum, at least in percentages less than 0·50, had no effect upon either A_s or A_f. Consequently, neither formula requires a factor for molybdenum.

On this basis, A_s can be related to the chemical composition of a steel as follows:

$$A_s(^\circ\text{F.}) = 1{,}333 - (25 \times \%\ \text{Mn}) + (40 \times \%\ \text{Si}) - (26 \times \%\ \text{Ni}) + (42 \times \%\ \text{Cr})$$

Unlike A_s, the upper critical temperature is markedly influenced by carbon content, the effect of carbon being indicated by the slope of the A_3 line of the iron-carbon phase diagram. Over the 0·3–0·6% C range, A_f is lowered very nearly in direct proportion to the weight percentage of carbon. This enables us to express the effect of carbon—in steels containing 0·3–0·6% C, of course—in simple mathematical terms. When this effect is combined with the effects of individual alloying elements, the following formula results:

$$A_f(^\circ\text{F.}) = 1{,}570 - (323 \times \%\ \text{C}) - (25 \times \%\ \text{Mn}) + (80 \times \%\ \text{Si}) - (32 \times \%\ \text{Ni}) - (3 \times \%\ \text{Cr})$$

Some limitations of the formulas

Since both formulas are based upon the assumption that the effect of additional elements upon A_s and A_f is directly proportional to the weight percentage and also that the individual effects are algebraically additive in steel containing several alloying elements, the formulas are easy to calculate. However, they require the following compositional limitations: 0·3–0·6% C; 0–2% Mn; 0–1% Si; 0–3·5% Ni; 0–1·5% Cr; and 0–0·5% Mo. Fortunately, this composition range covers many of the standard A.I.S.I. low-alloy steels, several of which are listed in table 1. In this table, the measured and calculated values were rounded off to the nearest 5°F. in accordance with the probable experimental error to be expected in measurement. This is usually permissible because, as can be seen in the table, greater precision is not justified.

Although the calculated values of A_s differ from the measured values by as much as 15°F. in one instance, the mean deviation is only 5°F. with about as many calculated values on the high side as on the low side. Calculated values of A_f differ from the measured values by as much as 25°F. with a mean deviation of 6°F. Both critical temperatures, especially A_f, are influenced by segregation which is always present to at least some extent in commercial steels. Unfortunately, this factor, which may explain why the calculated value occasionally differs considerably from the measured value, cannot be readily evaluated.

When we tried to extend these formulas to steel compositions outside the recommended range, our calculated results became more unreliable with increasing alloy content. For reasons already discussed, it does not seem possible to develop one simple formula which would be satisfactory for all types of ferritic steel. Within the specified composition limits, however, these empirical formulas appear to be sufficiently reliable to be useful in planning heat treatments.

TABLE 1 *Comparison of measured and calculated A_s and A_f temperatures*

A.I.S.I. Number	C	Mn	Si	Ni	Cr	Mo	A_s Measured	A_s Calculated	A_f Measured	A_f Calculated
							°F.	°F.	°F.	°F.
C 1031	0·35	0·37	0·21	—	—	—	1,330	1,330	1,470	1,465
C 1045	0·47	0·57	0·20	—	—	—	1,330	1,325	1,420	1,420
C 1065	0·63	0·87	0·22	—	—	—	1,325	1,320	1,355	1,360
1335	0·35	1·85	0·19	—	—	—	1,295	1,295	1,430	1,425
1340	0·42	1·58	0·30	—	—	—	1,300	1,305	1,420	1,420
2340	0·37	0·68	0·21	3·41	—	—	1,225	1,235	1,350	1,340
3140	0·38	0·72	0·21	1·32	0·49	—	1,305	1,310	1,390	1,400
4037	0·35	0·80	0·24	—	—	0·25	1,315	1,320	1,465	1,455
4047	0·48	0·94	0·16	—	—	0·25	1,315	1,315	1,405	1,405
4130	0·33	0·53	0·27	—	0·90	0·18	1,355	1,370	1,465	1,470
4140	0·37	0·77	0·15	—	0·98	0·21	1,365	1,360	1,445	1,445
4150	0·44	0·95	0·23	—	0·93	0·21	1,350	1,355	1,425	1,420
4340	0·42	0·78	0·24	1·79	0·80	0·33	1,300	1,310	1,375	1,375
4640	0·36	0·63	0·19	1·84	—	0·23	1,280	1,275	1,395	1,395
5140	0·42	0·68	0·16	—	0·93	—	1,360	1,360	1,425	1,445
8630	0·30	0·80	0·29	0·54	0·56	0·21	1,330	1,335	1,450	1,460
8650	0·50	0·77	0·22	0·60	0·51	0·22	1,325	1,330	1,385	1,385
8742	0·44	0·90	0·25	0·44	0·54	0·22	1,320	1,330	1,435	1,410
86 B 50*	0·50	0·77	0·23	0·60	0·50	0·21	1,325	1,330	1,395	1,390

*Possible effect of 0·0016% B was neglected in the calculation

Low-temperature ageing of iron and low-carbon steel

IVAN HRIVŇÁK

A study of the low-temperature ageing of pure iron and low-carbon steel has shown the mechanism of precipitation of the nitrides. New data on the precipitation of oxides of iron were also obtained. In particular, precipitation of the oxides led to definite experimental confirmation of the dislocation model of the high-angle grain boundaries, as a synthesis of parallel Burgers boundaries. By a further study of these boundaries on thin foils of aluminium it has not yet, however, been possible to prove this model experimentally*

continued from last month

Precipitation of iron oxides in the pure iron

IN ORDER to obtain data on the precipitation of oxides, we had to study them above the range of stable existence of the nitride precipitates.

For the study of the iron oxides a temperature of 750°C. was chosen. Specimens of the high purity iron were homogenized for two hours at 1,200°C. in an inert atmosphere and then quenched in water. By means of collodion extraction replicas it was determined whether the oxide particles were dissolved. In order to guard against any doubts whether oxide particles might not precipitate in the interval between quenching and preparation of the specimen, the time between quenching and preparation of the collodion, extraction replica was less than four minutes. As a result of the heat treatment carried out, in view of the low cooling rate the structure was ferritic. It was established objectively that the majority of the oxide precipitates were dissolved, and fig. 13 is a photograph of the least favourable area, *i.e.* that with the greatest number of particles. After this homogenization the effect of the multi-step boundaries was most markedly recognizable. The majority of the individual oxide precipitates were liberated at these boundaries, as is indicated by the arrows.

Then the homogenized specimens were heated in a salt bath to 750°C., and were held at this temperature for two and 10 min. and one and 50 h., with subsequent quenching in water. After two minutes no essential changes in the nucleation of the oxide precipitates were established by comparison with the homogenized state. Even after heating for one hour there is incomplete nucleation and growth of oxide particles, which were identified by electron diffraction as α–Fe_2O_3 (table 3). Fig. 14 characterizes the morphology of these particles in the vicinity of a boundary between ferrite grains. By means of etching on the [100] plane it was possible to show that the Fe_2O_3 particles precipitate in the [100] planes of the α–iron, and form the most concentrated zone at the grain boundary. After heating for 50 h. at 750°C., almost all the lines of the orthorhombic α–Fe_2O_3 were already revealed (table 3). Morphologically in fact, the formations were very marked and modified in the vicinity of the grain boundaries. In fig. 15 may be seen a multiple line of oxide particles, which change their orientation in the vicinity of the grain boundary. There is a similar occurrence in the further fig. 16. Both specimens may be compared with the clearly marked, multi-step boundaries, which were published in an earlier work.[1]

During the low-temperature ageing of the Johnson, Matthey iron only very isolated carbide precipitates were found. This is because part of the atoms of nitrogen in the nitrides can be replaced by atoms of carbon, thus forming similar carbonitrides, and also because the carbon content in this iron was exceptionally low.

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*First publication. Translated by M. de O. Tollemache. The author is with the Welding Research Institute in Bratislava, Czechoslovakia. The first part of the article was given in last month's METAL TREATMENT and is concluded in this issue.

Low-temperature ageing of the commercial steel, CSN 11370·3

In order to establish whether the results obtained during the ageing of spectrographically pure, Johnson, Matthey iron have general validity, experiments were initiated to study the low-temperature ageing of commercial steel to specification ČSN 11370·3 also. Specimens of this steel were austenitized at 950°C. for 4 h. with subsequent cooling in air to about 700°C., followed by quenching in water. Material heat treated in this way was then aged for 10 min, 1, 10, 50 and 100 h. at temperature of 100, 200 and 300°C.

1. *Ageing at* 100°*C.* After heating for 10 minutes, by comparison with the initial, normalized state no substantial changes were discovered in the structure of the material. Only the boundaries of the mosaic structure were for the most part marked out by plate-like precipitates, which could be ε–Fe_3C. Their morphological configuration is indicated in fig. 17. Even after heating for one hour no spontaneous precipitation was detected. After heating for between 10 and 50 h. it becomes possible to identify characteristic, rod-like or moderately plate-like, precipitates, which have nucleated in the same way as in the pure iron at the lattice defects. After heating for 100 h. no substantial changes took place by comparison with the structure after heating for 50 h.

A typical example of the precipitation in the ferrite is shown in fig. 18. Pronounced, preferentially plate-like, precipitates are formed at the grain boundaries and at the boundaries of the mosaic structure. While the distances between the precipitates at the boundaries of the mosaic structure vary around 800–1,000 Å (fig. 18), to which there are corresponding differences in the angles between the blocks of 20–15 min., the distances between the precipitates at the grain boundaries vary around 50–100 Å. Since the grain boundary in fig. 18 is formed as a simple, Burgers boundary, so the relative difference in the orientation of the grains is δ = 2–3°.

Apart from precipitates at the boundaries of the grains and the mosaic structure, it is possible to identify marked formations of complex lines of ε–Fe_3N. The mechanism of the formation of the nitride precipitates will be similar to that in fig. 6.

Accurate identification of these nitrides is difficult, since electron diffraction by back reflection cannot be used on account of masking by the pearlitic cementite, and the quantity of particles for transmission diffraction in extraction replicas is too small to obtain satisfactory reflections. On this account it is possible to judge only from their morphological similarity that these particles are ε–Fe_3N nitrides, though the plate-like precipitates at the boundaries of the grains and of the mosaic structure could also be ε–Fe_3C.

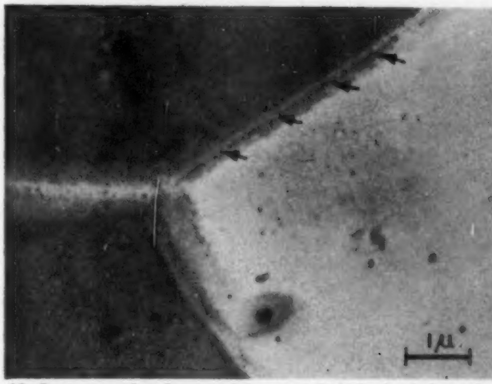
2. *Ageing at* 200°*C.* At 200°C. it was possible to identify the first precipitates after heating for only 10 min. But the precipitation is spontaneous, and does not pinpoint the lattice defects or dislocations, as applied at 100°C. Nor are the boundaries of the mosaic structure demarcated. During subsequent ageing formation of characteristic platelets occurs, whose morphology after heating for 50 h. is shown in fig. 19. Precipitation of these platelets ceases after heating for 100 h. From the morphological aspect it is probably a matter of a transition from ε–Fe_3N through ζ–Fe_2N to α''–$Fe_{16}N_2$.

3. *Ageing at* 300°*C.* In the same way as at 200°C., precipitation starts after heating for only 10 min. in the form of fine, plate-like particles which have

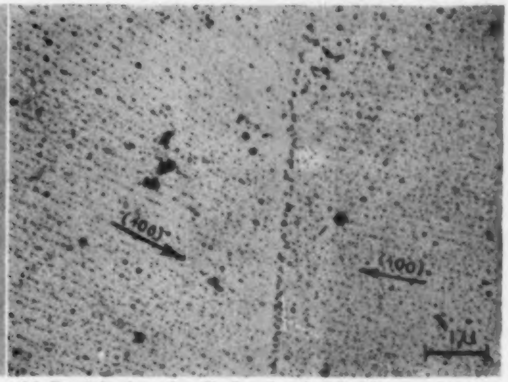
TABLE 3 *Reflections for α–Fe_2O_3 in pure iron*

No.	1,200°C./2 h./water 750°C./1 h./water		1,200°C./2 h./water 750°C./50 h./water		ASTM α–Fe_2O_3*	
	d Å	Intensity	d Å	Intensity	d Å	I/I₁
1	—	—	2·71	m.w.	2·71	100
2	2·64	w. diffuse	—	—	2·55	70
3	—	—	2·35	w.	2·35	10
4	2·12	w. diffuse	—	—	2·21	50
5	—	—	2·09	m.w.	2·08	10
6	—	—	1·84	w.	1·85	80
7	—	—	1·70	m.w.	1·70	100
8	1·58	s. diffuse	1·61	w.	1·61	50

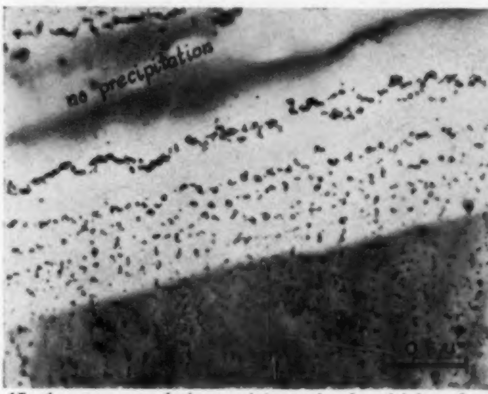
*Bohm and Ganter, *Z. Krist.*, 1928, **69**, 19.
Intensity: v.s., very strong; m.s., medium strong; s., strong; m.w., medium weak; w., weak; v.w., very weak.



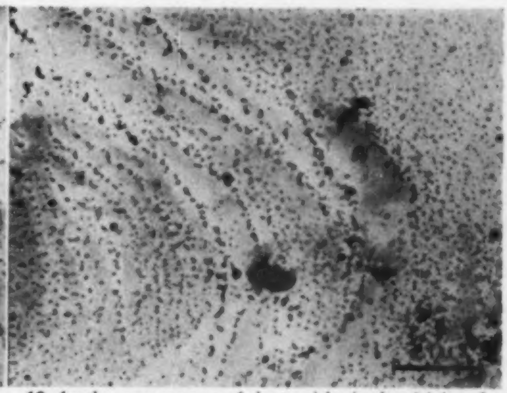
13 *Structure after homogenizing at 1,200°C. for 2 h. and quenching in water. Collodion extraction replica*



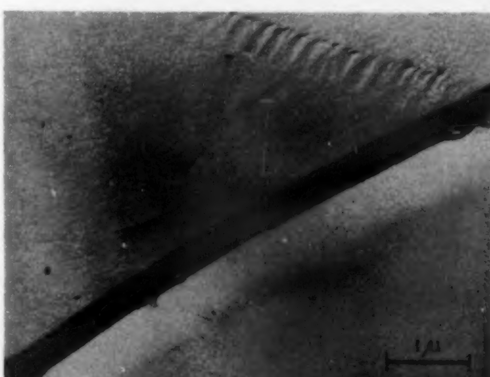
14 *Precipitation of α–Fe_2O_3 after heating for one hour at 750°C. Collodion extraction replica*



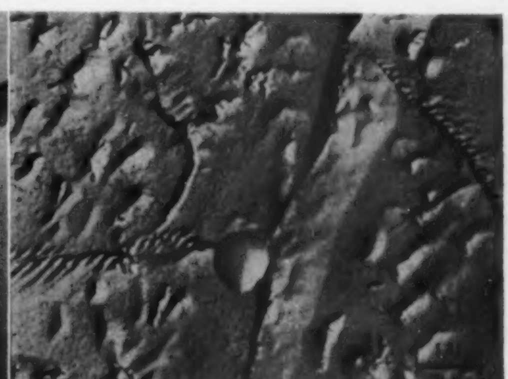
15 *Arrangement of the precipitates in the vicinity of a multi-step grain boundary. Collodion extraction replica*



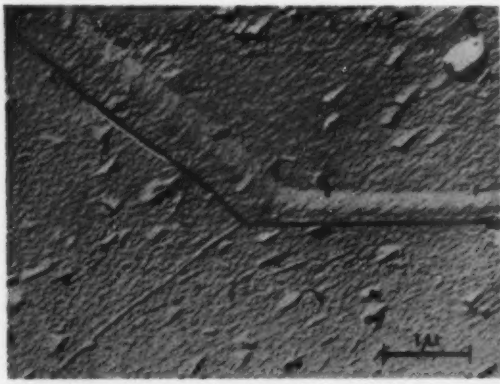
16 *Another arrangement of the particles in the vicinity of a grain boundary. Collodion extraction replica*



17 *Arrangement of the precipitates in steel ČSN* 11370·3. *Carbon extraction replica*

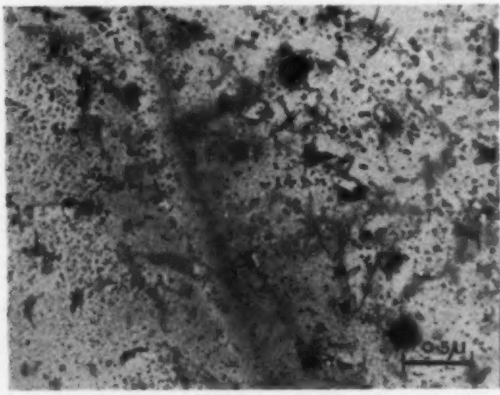


18 *Nitride precipitates in the commercial steel. Carbon extraction replica*

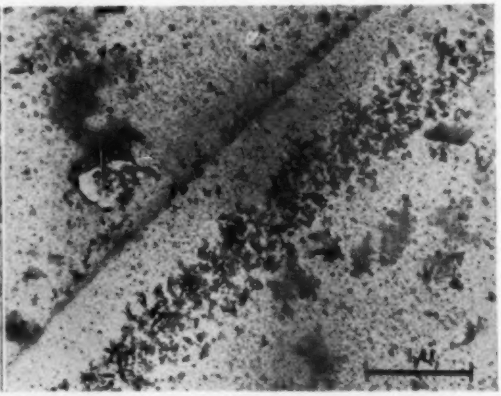


19 *Nitride particles after heating for 50 h. at 200°C. Carbon extraction replica*

20 *Precipitates of nitrides and oxides. Carbon extraction replica*

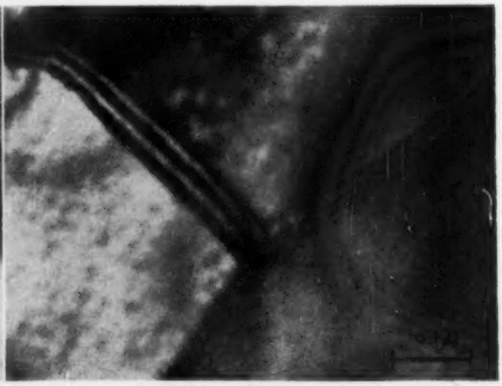


21 *Extracted oxide and nitride particles. Collodion extraction replica*



22 *Another arrangement of the oxide particles in the vicinity of a grain boundary. Collodion extraction replica*

26 *Discrete dislocations (precipitations) at a grain boundary in high purity aluminium* (99·999%). *Thin foil*



27 *Multiple arrangement of discrete dislocations at a grain boundary in aluminium foil*

nucleated in the interior of the ferritic grains. It appears that during longer periods of ageing, mainly above one hour, the particles are once again dissolved. It is, of course, possible that the particles also grow, so that their total number is diminished. The morphology of the nitride particles after heating for one hour, even though they are comparatively isolated, is shown in fig. 20. In fig. 20 we see the junction of several grains, and certain boundaries are multi-step. Attention should also be paid to the fine, oxide particles, but the regularity of their distribution in the [100] planes of the α–Fe is not typical of this commercial steel.

After heating for 50 h. the nitride precipitates can be identified only exceptionally, while after heating for 100 h. they are already completely dissolved in the structure. This means that the temperature of 300°C. is already the upper limit of the formation of the nitride precipitates in this steel, and ageing experiments were not therefore carried out at 400°C.

Electron-diffraction analysis of the commercial steel

Study of the nitride particles by means of electron diffraction encountered great problems over the method to be employed. The back reflection method could not be used, since only Fe_3C reflections were obtained, and during extraction and diffraction of the particles their low density obstructed the approach, so that it was impossible to obtain a reliable spectrum. By means of collodion extraction replicas, however, it was possible to extract the oxide particles, from which transmission diffraction patterns were obtained.

In fig. 21 is the extraction replica from a specimen heated for one hour at 200°C. On the specimen presented the boundary of the ferritic grains is sufficiently clearly visible, and also the irregular distribution of the fine oxide particles. Around them in the structure there are also acicular, ε–Fe_3N nitrides, and several much coarser particles.

Precipitation of the oxide particles was studied in greater detail at the 300°C. isotherm, at which selective diffraction was carried out on extraction replicas in the ranges of 20μ and 3μ. The results are shown in tables 4 and 5. The results show good agreement with those for the α–Fe_2O_3 oxides, as tabulated by ASTM. The morphology of the oxide particles after heating for one hour at 300°C. is characterized by fig. 22. Beside the marked, globular formations, in the figure are to be seen distinct dark marks of the oxides, and also short, rod-like or plate-like, nitride precipitates.

In general it may be stated that the regularity of the orientation of the α–Fe_2O_3 oxides is not as high as in the instance of the pure iron, and that their integral quantity is greater. This is probably also due to the fact that in these commercial materials other types of oxides can also occur.

Hardness measurements

On the specimens of the high purity, Johnson, Matthey iron microhardness measurements were made by the Hanemann method after heating at 100, 200, 300 and 400°C. In each instance the average values from 5 measurements are given in fig. 23. On the course of the hardness curves two maxima may be established: the first, pronounced maximum corresponds to the initial state of precipitation of ε–Fe_3N, whereas the second to a lesser extent reflects the transformation from ε–Fe_3N through ζ–Fe_2N into α''–$Fe_{16}N_2$.

The pronounced first maximum could only be recorded on specimens heated at 100°C., because

TABLE 4 *Selective diffraction spectrum from the 20μ range for α–Fe_2O_3 at 300°C.*

No.	10 min. at 300°C.			1 h. at 300°C.			50 h. at 300°C.			100 h. at 300°C.			ASTM α–Fe_2O_3	
	R_{mm}	Intensity	d Å	R_{mm}	Intensity	d Å	R_{mm}	Intensity	d Å	R_{mm}	Intensity	d Å	d Å	I/I_1
1	9·8	m.s.	2·50	9·1	m.s.	2·50	9·7	s.	2·59	9·0	s.	2·50	2·51	75
2	11·1	w.	2·20	10·4	w.	2·18	10·8	m.s.	2·24	10·0	s.	2·25	2·20	18
3	—	—	—	12·2	s.	1·86	—	—	—	11·5	w.	1·95	1·84	63
4	14·5	s.	1·69	13·5	v.w.	1·68	14·3	w.	1·69	13·3	w.	1·69	1·69	63
5	16·3	s.	1·50	15·25	m.s.	1·49	—	—	—	15·1	v.w.	1·49	1·49	50
6	16·9	m.s.	1·45	15·7	m.s.	1·45	16·7	m.s.	1·45	15·5	s.	1·45	1·45	50
7	18·0	v.w.	1·35	16·7	v.w.	1·35	—	—	—	—	—	—	1·35	3
8	20·5	m.s.	1·19	19·1	w.	1·19	—	—	—	—	—	—	1·19	8

Intensity: v.s., very strong; m.s., medium strong; s., strong; m.w., medium weak; w., weak; v.w., very weak.

it lies in the vicinity of 10 min. On the remaining specimens this maximum lies between 0 and 10 min. heating time.

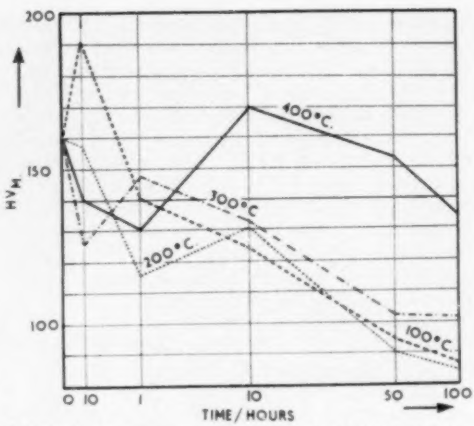
For the specimens which were heated at 400°C. it is impossible to interpret the hardening sequence, since the temperature of 400°C. is outside the range of the stable existence of the nitride precipitates. On this account there remains only the precipitation of the oxides to explain the effect of hardening after 10 min. heating.

The microhardness sequence was also measured on the commercial steel to specification ČSN 11370·3, and the values are shown in fig. 24. At 100°C. the maximum after heating for one hour corresponds to the initial state of precipitation of ε–Fe_3N, for these particles had not yet been morphologically recorded. In accordance with the morphological study, formation of α''–$Fe_{16}N_2$ does not occur even after heating for 100 h., and therefore no second hardness maximum is revealed. At 200°C. the first maximum occurs before the elapse of 10 min. heating, for definite precipitates were already observed. It is probable that the maximum hardness value of the ferrite is greater, but lies between 0 and 10 min. At 200°C. after heating for 50 h. it is possible to establish a definite growth in hardness connected with the transformation from ε–Fe_3N through ζ–Fe_2N to α''–$Fe_{16}N_2$.

At 300°C., in accordance with the morphological study, no particularly marked changes in the hardness sequence occur.

Discussion

Earlier it was assumed that precipitation of the nitrides from a supersaturated solid solution of iron and nitrogen starts with α''–$Fe_{16}N_2$, which then transforms into the cubic γ'–Fe_4N. This opinion was mainly defended by Jack,[17, 8, 14, 18] who assumed that in the Fe–N system α''–$Fe_{16}N_2$ corresponds to the hexagonal ε–Fe_3C.



23 *Microhardness curves of specimens of the high purity iron*

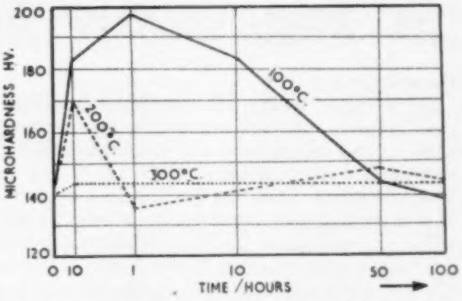
During the low-temperature ageing of the high purity, Johnson, Matthey iron it was established that at temperatures of 25, 100, 200 and 300°C. precipitation starts with the hexagonal nitride ε–Fe_3N, and that after longer periods of heating this nitride transforms through the phase ζ–Fe_2N into α''–$Fe_{16}N_2$ and finally into the stable form γ'–Fe_4N.

At a temperature of 100°C. precipitation of ε–Fe_3N starts after heating for only 10 min. The

TABLE 5 *Selective diffraction spectrum from the 3μ range for α–Fe_2O_3 at 300°C.*

No.	10 min. at 300°C.			1 h. at 300°C.			50 h. at 300°C.			100 h. at 300°C.			ASTM α–Fe_2O_3	
	R_{mm}	Intensity	d Å	R_{mm}	Intensity	d Å	R_{mm}	Intensity	d Å	R_{mm}	Intensity	d Å	d Å	I/I_1
1	—	—	—	7·6	s.b.	2·69	7·6	s.d.	2·69	7·6	s.d.	2·69	2·69	100
2	—	—	—	—	—	—	8·1	p.	2·51	8·1	s.d.	2·51	2·51	75
3	9·6	s.d.	2·20	9·25	m.s.	2·21	9·30	m.s.	2·20	9·2	m.s.	2·22	2·20	18
4	12·5	s.d.	1·69	12·1	m.s.	1·69	12·0	p.	1·69	12·2	s.d.	1·68	1·69	63
5	—	—	—	—	—	—	—	—	—	14·2	v.v.w.	1·44	1·45	50
6	16·1	v.v.w.	1·31	15·6	w.	1·31	—	—	—	15·2	v.v.w.	1·35	1·31	18
7	—	—	—	18·0	w.	1·14	—	—	—	—	—	—	1·10	10
8	—	—	—	—	—	—	19·6	p.	1·06	19·3	v.v.w.	1·06	—	—
9	—	—	—	21·3	w.	0·96	—	—	—	—	—	—	0·96	10

Intensity: s.b., strong body; s.d., strong diffuse; p., points; m.s., medium strong; v.v.w., very, very weak; w., weak.



24 *Microhardness curves of specimens of steel ČSN* 11370·3

first particles of ε–Fe_3N are coherent with the α–Fe. And although these relationships in orientation were obtained only from the morphological studies, it is possible to check and confirm them. The first particles of ε–Fe_3N are also parallel with the lines of oxide precipitates. Concerning the particles of α''–$Fe_{16}N_2$ it is known from the literature[8, 14, 16, 17, 18] that they are coherent with the [100] planes of the α–Fe. But these nitride precipitates are parallel with the lines of oxide particles. Therefore the particles of ε–Fe_3N are also coherent with the [100] planes of the α–Fe. Morphologically this coherence was established by means of etching the ferrite on the [100] plane.

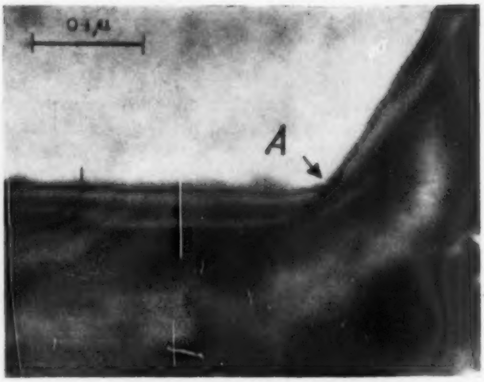
The ε–Fe_3N precipitates nucleate at the dislocations and other lattice faults. This nucleation is also pronounced on the boundaries of the mosaic structure (veining). In the further phase of heating the relationships in the orientation are disrupted, and the initial transformation from ε–Fe_3N into ζ–Fe_2N takes place. Finally, the transformation of ζ–Fe_2N into α''–$Fe_{16}N_2$ will proceed. It is interesting that the precipitation of ε–Fe_3N does not start at the grain boundaries. This could mean that the areas of the ferrite grain boundaries are not areas with a high concentration of nitrogen. But it is also possible that, precisely because the grain boundary areas are areas with a high value of free energy, the atoms of nitrogen are not forced to pass into the precipitates, and that even after spontaneous precipitation the nitrogen atoms are therefore contained in the grain boundary areas, which are thus areas with an increased concentration of interstitial elements. This was, in fact, suggested by Tsou, Nutting and Menter,[5] in interpreting the discovery of γ–Fe lines from quenched specimens. The appearance of γ–Fe lines at the grain boundaries they explained by the fact that austenite continued to exist at the boundaries under the influence of the high nitrogen content in areas, for it is a strong austenite-forming element. In the present study, in no instance did we detect γ–Fe lines in specimens heat treated in a similar way, and it may rather be considered as proven that the concentration of nitrogen in the grain boundary areas is not higher than within the grains themselves.

Very convincing data were obtained concerning the precipitation of oxides, in particular concerning their modified, morphological configuration in the grain boundary areas. These oxide particles form in the grain boundary areas identical, multiple zones to those which were described in an earlier work[1] in which multi-step boundaries were defined. The quantity and prominence of the multi-step, ferrite grain boundaries, were nevertheless dependent on the duration of etching, which was the weak point in their interpretation. But in this instance the number of steps in fig. 15, for example, is conclusive, and is independent of the time of etching, whereby it was possible to prove that multi-step boundaries are an objective reality, independent of the etching of the surface. It is interesting that at each boundary there exists a so-called neutral zone about 1,000 Å in width, in which no precipitation of oxides takes place. At temperatures of 200 and 300°C. also, the method of precipitation of the nitrides is similar. At a temperature of 300°C. precipitation ends after heating for 100 h. with the cubic γ'–Fe_4N.

From the results of the study of the precipitation of the nitrides and oxides it is possible to provide a basis for, and also support, the model of the high-angle grain boundaries, which was outlined in our earlier work.[1] High-angle grain boundaries can also have a dislocation character. This can be the suitable, parallel piling up of several dislocation walls, shown diagrammatically in fig. 25. The relative difference in orientation between two neighbouring walls should not be greater than 1–2°. The experimental results, however, show especially that the modified precipitation of the oxide particles has considerable preference for this model. And the energies of these boundaries, as has been shown experimentally by Holländer[27, 28] show good agreement with the measured values.

So far as the model of the high angle grain boundaries is concerned, this was obtained from indirect experiments on the basis of the effect of the multi-step grain boundaries and by the

25 *Diagram of the dislocation model of a high-angle grain boundary*



28 *Change in the orientation of the extinction contours. Thin foil*

initial states of the precipitation of oxides and nitrides of iron.[1] In order to confirm this model by more exact experiments, a systematic study was made of the grain boundaries on thin foils by means of a transmission electron microscope. It must be stated, however, that results obtained on heated foils of aluminium with a purity of 99·999% (thickness before thinning 0·2 mm.), for instance, have so far not confirmed this model. And although in fig. 26, for instance, it is possible to distinguish not only the multistep boundaries, but also the discrete dislocations with spacings of 30–20 Å, to which, on the assumption of a simple Burgers boundary, there is a corresponding relative difference in orientation of 8 or 10°, these steps are not in one plane, but are caused by the thickness of the foil (about 1,000 Å), and therefore by a distinct width of the boundary surface, clinogonal to the plane of the foil. There is something similar to this in fig. 27, where the grain boundaries also have several steps. That these extinction contours are caused by the great width of the boundary surface is also clearly shown by fig. 28, where at point A a change in its orientation occurs, and the orders of the extinction contours change.

It is therefore necessary to emphasize that there is still disagreement over the problem of the mechanism of the grain boundaries; low angle boundaries are formed by dislocations, which can be shown not only on foils, but also in the study of precipitation processes, during which the particles nucleate at these dislocations.

It has not proved possible to show by a study of thin foils dislocations in high angle boundaries with spacings of about 10 Å. Likewise it has not yet proved possible experimentally to substantiate the proposed model[1] by direct study of thin foils. Progress is being made in the study, and it will be published as a separate report.

Conclusions

By a study of the low-temperature ageing of pure, Johnson, Matthey iron with a high content of nitrogen and oxygen, and also of commercial, low-carbon steel to specification ČSN 11370·3, it has been possible to show that precipitation of nitrides of iron from a super-saturated Fe–N solution starts with the hexagonal ε–Fe_3N, which precipitates at the dislocations and other lattice defects. There is marked nucleation of ε–Fe_3N at the boundaries of the mosaic structure (veining). The grain boundaries are not areas where precipitation of ε–Fe_3N is great. The initial states of the precipitation of ε–Fe_3N are coherent with the [100] planes of the α–Fe. Precipitation of ε–Fe_3N was observed at 25, 100, 200 and 300°C. The hexagonal ε–Fe_3N transforms into α''–$Fe_{16}N_2$ through the transitional nitride ζ–Fe_2N, which has no marked relationships in orientation to the basic planes of the α–Fe. The final stable product of the precipitation of the nitrides is the cubic γ'–Fe_4N. The precipitation of ε–Fe_3N, just as the transformation from ε–Fe_3N through ζ–Fe_2N into α''–$Fe_{16}N_2$, is accompanied by an increase in hardness.

The mechanism of the precipitation of the nitrides is also similar in commercial steel to specification ČSN 11370·3. Here also precipitation of ε–Fe_3N starts at the dislocations and other lattice defects.

New data were obtained concerning the precipitation of oxides of iron. It was shown that oxygen can precipitate in a supersaturated solid solution of α–Fe. Precipitation of oxides of iron was investigated in spectrally pure iron at 750°C. and in commercial steel to specification ČSN 11370·3 at temperatures of 100, 200 and 300°C. The oxides of iron precipitate as α–Fe_2O_3. Morphologically they form disc-shaped formations of 500–800 Å in diameter, which precipitated in the pure iron in the [100] planes of the α–Fe with a high degree of symmetry. At the high-angle grain boundaries this symmetry is destroyed, and the oxides of iron precipitate in several lines, parallel to the direction of the boundary. At the same time the boundary lines themselves form a 'neutral zone,' in which precipitation of oxides does not take place.

In particular, precipitation of the oxides led to definite experimental confirmation of the dislocation model of the high-angle grain boundaries, as a synthesis of parallel Burgers boundaries. By a further study of these boundaries on thin foils of aluminium it has not yet, however, been possible to prove this model experimentally. The study is in progress.

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Beryllium bronze

Use in electron microscope grids

ALTHOUGH the market price of beryllium is high, the fact that its content rarely exceeds 3% in the alloys used for engineering purposes means that cost does not stand in the way of utilization.

Probably the most important beryllium alloys are those formed with copper, cobalt, and nickel, and their strengths can be improved by heat treatment. A process of quenching and tempering can convert these alloys from their original soft condition into a spring temper state, which is invaluable for technical applications.

In beryllium bronzes, this property of toughening is most marked when the beryllium content ranges from 2·4–3·5%, although it is also apparent from 1·3% content upwards. After heating for some time to approximately 800°C. and then quenching in water, whereby the soft condition is retained, the metal can be rolled, etc. The alloy hardens if it is afterwards tempered at temperatures of 400°C.

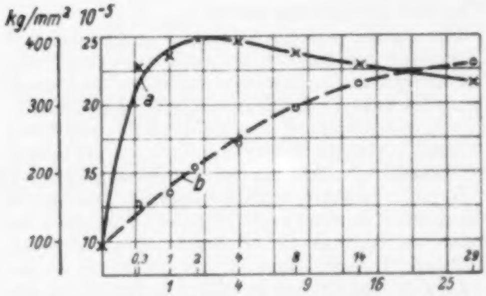
The beryllium content of the particular alloy, the pervious treatment, *i.e.* the extent to which it has been rolled, and the duration and temperature of the tempering process, determine the degree of hardness attainable.

Physical properties

As distinct from beryllium-copper, beryllium-bronze differs appreciably from other bronzes in its superior physical characteristics.

Without heat treatment, a bronze containing 2·5% beryllium has a hardness after quenching of some 100 Brinell units, but by heat treatment can be raised to approximately 400 Brinell units. On the other hand, a toughened bronze containing 2·5% beryllium approaches the strength of good spring steel, and is far stronger than aluminium-bronze, double-rolled to attain spring hardness. Either an extraordinarily high strength with low elongation, or a relatively high strength with great elongation, may be arrived at by varying the heat treatment. Very little sign of fatigue is shown by beryllium bronze, which possesses a high elasticity. A helical spring of beryllium-bronze withstood 25 million vibrations in an endurance test without losing any of its spring power. As a rule, springs do not usually withstand more than a few hundred thousand vibrations when made of phosphor bronze.

The electrical conductivity of a 2·5% beryllium-bronze ranges from approximately 17–19, compared to 7–10 for phosphor bronze. Hence structural parts of electrical equipment when of beryllium-bronze can be made about half the size.



1 *Showing results of heat treatment of a copper-beryllium alloy containing 2·5% beryllium. (a) Hardness; (b) Electrical conductivity. The abscissa shows the duration of tempering in hours, and the ordinate the electrical conductivity, together with the hardness (kg./mm.²). The alloy specimen here has been heated to 840°C. and quenched in water*

With the thermal conductivity of electrolytic copper taken as 1, that for beryllium-bronze is 0·4.

It is scarcely possible for a phosphor-bronze casting to exceed an electrical conductivity of 44, where that of electrolytic copper is 60. With copper that has been reduced with beryllium, however, an electrical conductivity as high as 56 can be obtained.

The size of cast parts of electrical plants can thus be reduced by some 25%, which means an appreciable saving of metal, and a reduction in weight.

Some applications

Beryllium-bronze can be used to advantage in electrical applications wherever the saving of material and weight of current-carrying parts justifies the higher price. The same is true of engineering uses, where greater hardness and strength justifies its application in parts subjected to mechanical strain. This is so particularly in the case of springs and small constructional parts, where the price of the part is of little moment compared with the price of the whole machine.

Amongst items made of the alloy are brush-holder springs and contact tips for electric motors, highly-stressed springs in telephone and signalling installations, and moulds for the casting of select varieties of ceramic material. In a number of parts where it is desirable to avoid magnetizing, or there is a danger of rusting, steel can profitably be replaced by beryllium-bronze. The latter alloy with a content of from 0·9–1·5% beryllium has been developed as a bearing alloy of recent years. This material, in the form of bearing bushes, when exposed to endurance tests, showed only about one-sixth of the wear of normal tin bronze, while no attack was apparent on the shaft.

Electron microscope grids

The minute perforated discs, or grids, employed in electron microscopes, are made from beryllium-bronze by use of an ingenious method. These small items are only 2 mm. dia., and have holes in them which, to the unaided eye, are invisible, only being detected under the magnifying glass, but yet have to be accurate to within the closest tolerances.

In order to accommodate all details, drawings of the discs, 6 in. dia., with the holes in position, are made on large sheets of white paper. A large number of these drawings are prepared on the sheets, so that all may be photographed at the one time. A high-grade plate camera is essential for taking the photograph, but, in place of the usual light-sensitive emulsion plate, a plate of gelatin is substituted. This is first subjected to 'bichromating,' *i.e.* immersion in potassium dichromate solution.

After subjecting to a relatively lengthy exposure, the bichromated gelatin plate is removed, washed in water which removes unaffected areas and provides a negative of the discs, in the form of flat and upraised sections. These have now been reduced from 6 in. to 2 mm. dia. A practical point is that, while each disc is ultimately independently electrodeposited, a connecting link permits the deposition to take place as with a plate—hence the discs will not fall out individually.

The bichromated gelatin is given immersion in a conducting medium so that current will be systematically carried. A solution of copper sulphate is used as the electrolyte, a strip of beryllium-copper as the anode, and the gelatin plate linked-up as the cathode, all of which are accommodated in a small glass tank.

These anodes and cathodes measure some 3 in. by $1\frac{1}{2}$ in., which means that, even allowing for a border section, many hundreds of discs may be deposited at the one time. In place of the 16% copper-sulphate solution containing 4% copper and 10% sulphuric acid, deposited at 10 amps./sq. ft., for normal depositions, a much more dilute solution containing about 1% acid is used, while a fraction of this amperage gives best results.

Beryllium is deposited with the copper in much the same manner as the deposition of zinc and copper in making electrolytic brass. The brightly deposited plate is removed, washed in water, and pressed with the fingers to dislodge the individual 2-mm. discs. Each disc is inspected under the microscope to ensure that all holes are perfect before being dispatched.

Low-temperature ageing of iron and low-carbon steel

concluded from page 240

Acknowledgments

The author wishes to thank the director of the Welding Research Institute, Academician J. Čabelka, for the exceptional interest with which he has studied the solution of this problem, and for numerous discussions, especially concerning the precipitation of oxides.

The author likewise considers it his pleasant task to thank V. Drahoš and A. Delong, of the Czechoslovak Academy of Sciences in Brno for collaboration in the experiments, especially in connection with the study carried out on thin foils by means of the Czechoslovak experimental, electron microscope with a high power of resolution.

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As foreshadowed in last summer's announcement by the chairman, Mr. Allen L. Stock, the Morgan Crucible Co. Ltd. ceased to trade on April 3 and became a Holding Company. From that date, its responsibilities for production, trading, research and development have been assumed by the following five new wholly owned subsidiaries: Morganite Carbon Ltd., Battersea, S.W.11; Morganite Crucible Ltd., Norton, Worcester; Morganite Electroheat Ltd., Wandsworth, S.W.18; Morganite Research and Development Ltd., Battersea, S.W.11; Morganite Exports Ltd., Battersea, S.W.11.

Dewrance & Co. Ltd. announces the formation of the Dewrance Metals Division. This will consist of the foundry at Hillington and the Special Alloys Division in London.

The new division will have its own Board of Management and will be responsible for the production and sales of high quality non-ferrous castings, nickel alloy castings, stainless steel castings, 'Endewrance' hardfacing and high temperature brazing alloys.

Engineering, Marine, Welding and Nuclear Energy Exhibition

British engineering exports now account for 43% of the country's total overseas earnings from manufactured goods and produce, and the Engineering, Marine, Welding and Nuclear Energy Exhibition, held last month at Olympia, London, has become a landmark in the exhibition calendar. More than 500 exhibitors occupied Olympia's three main halls and their galleries. If there had been more room, the number would have been even greater, especially the number of foreign exhibitors. The exhibition, held every two years, covers the whole field of mechanical engineering, together with such ancillary processes as corrosion prevention, radiography, metal refining, lubrication, testing and measuring, mechanical handling and protective clothing. So also is every branch of shipfitting and ship construction. Nuclear equipment was found on about 40% of the stands. There was a separate welding section of 43 stands. The following review, which has no pretensions to comprehensiveness, selects some of the items of metallurgical interest

THE ACCENT was on automation on the *Gas Council's* stand. Gas industry research teams have played a large part in bringing push-button control to industrial appliances and the most recent successes were on show for the first time. From a control panel on the front of the stand, visitors were able to light up a forge furnace or start an air heater, one of a range for use in industrial ovens. Also connected to this centre panel was a packaged conversion burner for process air heaters and other industrial uses. It was developed by the North Western Gas Board's industrial gas development centre at Manchester and is the first British-made gas unit ready 'packaged'—complete with fan, automatic ignition and all control equipment.

Another development which was seen for the first time was a brass billet heating furnace designed by the South Western Gas Board. This furnace, of entirely new design, handles billets 3 in. long and up to 2 in. in diameter and is for hot brass stamping. An automatic syntron feeder is fitted and the billets are carried down a vertical furnace which occupies a space of up to 3 ft. square. The furnace can be set to automatically discharge billets at a predetermined rate or singly by the operator pushing a button. Efficiency is high, with maximum operating comfort and high production rates. Industrial Furnaces Ltd. are making the furnace for the South Western Gas Board.

Flash melting

The North Eastern Gas Board began work early last year on the development and design of a furnace for the rapid melting of non-ferrous metals. A series of development projects were carried out resulting in the design of the furnace on show. The unit has a melting capacity of approximately 100 lb. per charge and incorporates load recuperation in addition to combustion air pre-heating. The general sequence of operation is to place in the load-recuperation section the entire 100-lb. charge, which may consist of pre-alloyed billets, scrap, etc. Normally, the charge would remain in this section for a period of 8–10 min., while the previous 100-lb. charge was being melted in the melting section. The furnace exhibited was capable of doing 100-lb. melts in about 8 min. and has an hourly capacity of some 5–5½ cwt. (Fig. 1.)

On production trials, the unit proved to be very successful in operation from at least three aspects: 1, A very-much-improved quality of metal cast as compared with crucible furnace techniques; 2, a marked reduction in metal loss during the process; and 3, the fuel consumption per pound of metal is

very much reduced as compared with present-day methods. There is a continual discharge of molten metal into a holding section or pot which is maintained with a small auxiliary burner at a temperature suitable for casting. This technique reduces metal losses.

The arrangement and disposition of the burners used for firing this furnace are such that any type of atmosphere required adjacent to the metal being heated can readily be achieved and these conditions can, if necessary, be varied in accordance with the types of material being melted. During the time the initial charge is in the load-recuperation section, it is general for it to be raised to a dull red heat prior to its insertion in the melting section. Under normal conditions the combustion air is pre-heated to something in excess of 300°C.

Induction billet heating

The main exhibit of *Garringtons Ltd.* was an automatic induction billet heating unit designed to heat steel billets 1–2 in. square or round, 2–9 in. long, to a temperature of 1,250°C. at a production rate of 2,000 lb./h. A new feature of the heater is the continuous billet feed to eliminate electrical fluctuations by giving constant billet conditions within the heating coil. The feed device consists of a vibrator conveyor together with a double belt device which is easily adjustable to suit different billet sizes. (Fig. 2.)

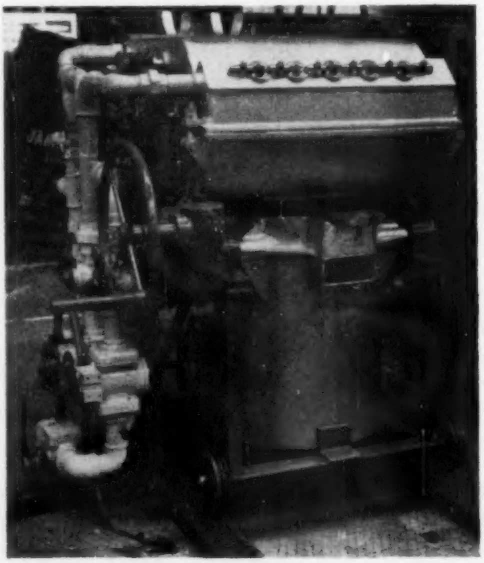
Included among the other exhibits of Garringtons' manufacture were: a single-shot heating coil designed to demonstrate the rapid heating obtainable with induction heating; and a pair of medium-frequency isolating switches housed in a cubicle and connected as a means of transferring the medium-frequency supply from one unit to another.

The main exhibit is, of course, one unit out of a large range of billet-heating equipment designed for different billet sections and lengths, and for a variety of output ratings. Garringtons design and manufacture induction billet heating equipment for many other purposes, foremost amongst which are: billet heating of both ferrous and non-ferrous metals for extrusion, rolling and similar processes where the design of the plant is specially related to production processes. Special-purpose equipment is available for the continuous treatment of steel tube, bar, etc., and, where desirable, the induction-heating process is associated with alternative forms of radiant heating where this can offer advantages to the user. Garringtons are currently producing equipment for ingot heating where the induction-heating technique is used in close association with electrical radiation furnaces in order to reduce damaging side effects.

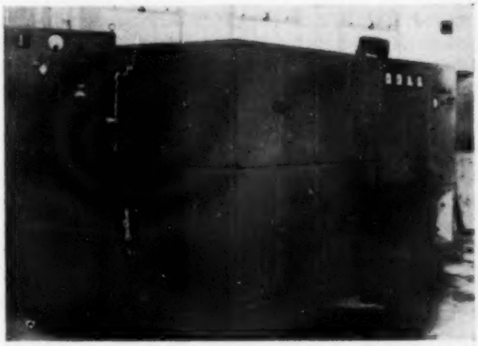
The resources available for development, research, and pre-production testing are the largest anywhere in Europe and possibly in the world. The division responsible for induction-heating activities also includes considerable facilities for design and manufacture of specialized mechanical-handling devices which can either form part of the production process involving induction heating, or, alternatively, can be a completely separate service available to industry. Similarly, the electrical engineering department embraces system controls covering a wide range of application which can, if necessary, be brought to bear on problems other than those associated with induction-heating techniques.

Stainless steels

The theme of the *Firth-Vickers Stainless Steels Ltd.* stand was on technical collaboration between producer, fabricator and designer. On display were welded specimens illustrating all techniques that can be applied to the welding of stainless steels. Alongside the procedures already well known and established, were examples of more recently introduced continuous-coated electrode welding together with the latest developments in shielded inert-gas metal arc welding. Firth-Vickers were pioneers in the welding of stainless steels and today, through continued close liaison with the manufacturers of welding plant, electrodes and ancillary equipment, they are able to offer special service in this field to users of stainless steels. Closely linked with the display of welded specimens were illustra-



1 *100-lb.-capacity flash melting furnace shown on the Gas Council's stand*



2 *Garringtons' automatic induction billet heating unit*

tions of how automatic-welding techniques are used in the production of expansion bellows. In addition to illustrating modern fabricating methods, these show how readily stainless steels respond to these processes.

The development of new materials has created specialists upon whom engineers and designers must rely for technical guidance and information, and since the advent of stainless steel close collaboration has been maintained between Firth-Vickers and engineers and fabricators. More recently, however, the industrial designer has sought guidance and advice in the use of special steels for particular applications.

In the field of new materials, the F.V.520 steels are being used for an increasing number of applications where their combination of strength, corrosion resistance, and weldability is required. The stand featured technical information on these steels together with examples of applications where their use has solved production problems. Other exhibits will illustrate how the steels lend themselves to normal methods of fabrication.

On show were parts from a turbo-exhauster where the discs are produced as centrispinnings with the blades subsequently riveted into position. F.V.520 here provided the required high strength and corrosion resistance that was not previously obtainable in one steel. A partly-produced component on a helicopter gearbox casing shows how F.V.520(S) sheet material in the softened condition responds to cold manipulation whilst a further section from this same gearbox casing illustrates how parts can be welded using normal methods for stainless steels.

An intricately-shaped rotor machined from F.V.520(B) solid bar in the normalized condition is an excellent illustration of the machining properties of this steel. The rotor will be subsequently precipitation hardened and is to be used experimentally in a sludge pump where it will operate under corrosive conditions with some abrasion. A nose cone which has been flow turned from F.V.520(S) sheet in the mill-transformed condition, shows the steel's capabilities in such an operation.

Nuclear energy

*The Hawker Siddeley Nuclear Power Company's** acquisition last September of Nuclear Engineering Ltd., who manufacture equipment for handling and using radioactive isotopes, has been followed by the announcement that the first university site licence has been granted to Queen Mary College, to whose special requirements the JASON Mark III reactor has been designed. The reactor is intended as a source of neutrons to drive fuel element lattice experiments.

The installed cost of a JASON reactor varies between £55,000 and £80,000, depending on the facilities it provides and the maximum operating power required. The JASON Mark III for Queen Mary College has a continuous power output of 10 kW. thermal and is capable of running three lattice experiments at once. The initial fuel supply will last throughout the life of the reactor, its U235 content being reduced by less than 0·1% per annum. The reactor is self-contained and simple to erect; it produces no harmful waste and can safely be installed in any suitable building, even in densely-populated areas.

Hawker Siddeley are working on schemes to provide universities throughout the world with complete nuclear research and training centres, equipped with JASON reactors and Automatron H.1 or T.2 irradiation units, made by *Nuclear Engineering Ltd.* which provide intense gamma radiations from Cobalt 60 sources of up to 50,000 curies and 10,000 curies respectively.

The capital cost of such a centre would be in the region of £345,000, while operating costs would be about £230,000 per annum, but a considerable part of this expenditure would be covered by direct earnings. Apart from pure research, the JASON reactor could be used as a producer of many different radioisotopes for medicine, agriculture and industry and in particular of the short-lived varieties.

Babcock & Wilcox Ltd. were showing models of nuclear steam-raising plant for merchant ships and for the 580-MW. nuclear power station to be built by the English Electric, Babcock & Wilcox, Taylor Woodrow atomic power group at Sizewell in Suffolk.

Simmering-Graz-Pauker A.G. exhibits covered the company's work on research reactors at Seibersdorf and Vienna. For Seibersdorf, a

*Both the JASON and the Automatron range of irradiation units were illustrated on the Hawker Siddeley stand.

5-MW. ASTRA research reactor, 80% of the mechanical components have been supplied, also the 500-h.p. diesel emergency power supply. Mechanical components and emergency power are being supplied for the 100-kW. TRIGA reactor in Vienna.

Nuclear exhibits by the *Talbot Stead Tube Co. Ltd.* included breeder thermocouple guide tubes and a model of a stainless-steel control rod with boron inserts. The company also showed a model of a mild-steel charging stand pipe, whose upper part consists of a concrete-filled outer tube containing four inner tubes, while the lower part is made up of a large tube with a smaller tube attached to its outer wall.

Axial fans with slotted blades, similar to those fitted in American nuclear submarines, were exhibited by *Keith Blackman Ltd.* who now manufacture them in Britain. The slotted-blade formation is said to give boundary-layer control and to extend laminar flow over a large part of the blade chord, resulting in high efficiency and high operating pressures at low speeds, with a corresponding reduction in turbulence and blade friction, noise, size and weight.

A resonance bending fatigue machine for investigating the fatigue strengths of tubes and welded joints was demonstrated in action by *Stewarts & Lloyds Ltd.* The machine is used for testing the tubes of nuclear boilers, which are subject to vibrations set up by the gas flowing over them.

The Nuclear Energy Trade Association's Conference was represented at the stand of the *British Engineers' Association*, where the starting up of a nuclear power station was demonstrated on a reactor simulator.

Short Brothers & Harland Ltd. were showing a scale model of the reactor simulator with a capacity of 200 amplifiers and an overall component error of less than 0·1%, which is being installed by the U.K. Atomic Energy Authority at their Calder Operations School. The machine has been designed to simulate the behaviour of a complete atomic power plant of the Calder Hall type, but can also be modified to simulate advanced gas-cooled reactors.

Teddington Aircraft Controls Ltd. claim to be anticipating nuclear developments over the next 50 years with a range of isolation cocks for small-bore nuclear instruments, designed for pressures up to 650 lb./sq. in. and temperatures up to 450°C. Leakage across the seat does not exceed 0·001 lb./h. at 600 lb./sq. in. Leakage to atmosphere is said to be zero.

Stacks of G.5 nuclear emulsion made by *Ilford Ltd.* are used in space-rocket capsules to obtain new information on the effects of cosmic radiations. Nuclear emulsion differs from ordinary photographic film in that the silver halide concentration is much higher and is coated about 50 times thicker, so as to make it easier to see the tracks of any charged particles which have struck it.

The 'Gammacell 220' irradiation unit, which was shown on the *Canadian Government* stand, has a fixed source of up to 54 Cobalt 60 rods arranged in 'squirrel cage' formation round a 6 in. dia. by 8½ in. high irradiation chamber. The chamber is raised and lowered electrically to receive specimens for irradiation. The unit is fitted with safety interlocks and is fully shielded; no external shielding or manipulators are required.

Two I.C.I. Divisions—Metals and Billingham—and *Marston Excelsior Ltd.* (an I.C.I. subsidiary company)—were at the exhibition. Exhibits were shown in four main groups—nuclear engineering; titanium; heat exchangers and heat-exchange products; and general engineering materials.

In the nuclear-engineering section were examples of zirconium, beryllium, hafnium, niobium and other new metals. 'Boroplast,' a boronized plastic material for use in radiation shields, was included in the display, while Marston Excelsior Ltd. were showing a wide variety of fabrications for nuclear-engineering purposes.

The Darlington Forge Ltd. (a wholly-owned subsidiary company of English Steel Corporation Ltd.) placed special emphasis on the company's products for the nuclear-energy industry, and the main feature of display was a 5-ton forged-steel gas-duct reinforcement ring. This ring, from which a test portion was cut away to reveal the cross-section, was of a similar type to several that had already been supplied by the Darlington Forge Ltd. for use at Bradwell Nuclear Power Station.

Welding

Palmer Aero Products Ltd. have developed a Precision-Orbital welding method which allows a pre-formed tube to be automatically joined to an end-fitting. A selection of stainless-steel and nickel-based alloy pipes welded by this method formed the highlight of Palmer's display.

Although designed primarily for the aircraft industry, this new process, a speedy, reliable and economical technique which supersedes conventional brazing methods, is of interest to all industries concerned with handling corrosive materials of elevated temperatures—especially the nuclear power industry. Weld crown dimensions and penetration bead dimensions can be accurately and consistently controlled, enabling designers to incorporate the weld bead—which is completely homogeneous—into design schemes.

Other exhibits were chosen to emphasize the comprehensiveness of Palmer's non-destructive testing service—which includes facilities for X-ray

and gamma-ray service (test house and mobile), magnetic crack testing, fluorescent crack testing, ultrasonic testing, pressure testing, air and hydraulic testing, low-temperature testing, film processing and the compilation of radiological reports.

If the advantages of modern high-speed welding methods are to be fully exploited, then a necessity arises in the production welding plant for a compatible method of preparing plate edges prior to welding operations. Preparation, by current methods, usually constitutes the major part of total welding cost; it is generally a slow process, often involving considerable handling and is rarely justified by the quality of finish. Pullmax machines for achieving this aim were shown by *Alfred Herbert Ltd.*, sole agents in the U.K.

The Pullmax X8 Quick Beveller is outstanding in that it produces better edges for X, Y, and V joints faster and more economically than by any other method. The machine can be supplied to produce angles of 30°, $37\frac{1}{2}$°, or 45°. Four grades of cutter are available with the machine, careful selection of which, for depth of bevel and nature of material, ensures the best possible joint. (Fig. 3.)

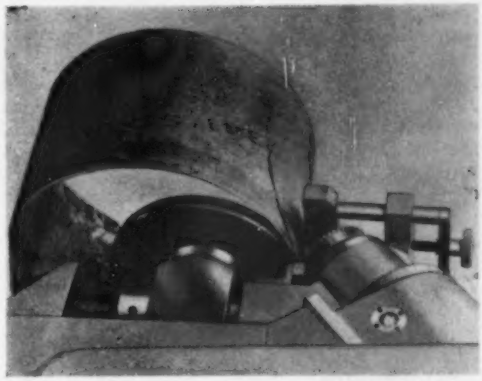
This versatile machine is not restricted to straight bevelling but will bevel irregular-shaped plate, tubes, beams, angle iron, circular, and even inner, radii of 8 in. or over. A special accessory can be supplied for suspension of the machine from an overhead gantry.

New equipment shown for the first time by *British Oxygen* included a lightweight straight-line- and circle-cutting machine, a slope-controlled rectifier, an automatic line-following device, and the latest range of lightweight electric welding generators. Also on show was a new vacuum insulated evaporator for liquid oxygen, nitrogen or argon.

With the new automatic line-following device, it will be possible to operate from simple line drawings, thus eliminating the use of conventional templates. The new device is demonstrated on the latest 'Bison' profile-cutting machine; the marketing date will be announced later this year.

The new, lightweight, portable straight-line- and circle-cutting machine, the PUG, will appear on the market within a few months, and will sell for about £40. This latest addition to the B.O.C. range of small portable machines is expected to bring high-quality mechanical oxygen cutting to an even wider range of industries.

A 6-ft.-long model of the *Dreadnought*, Britain's first nuclear submarine, was exhibited by *Murex Welding Processes Ltd.* Over a million Murex electrodes were used for the manual arc-welding of this new submarine which is the largest ever to be built in Great Britain. The *Dreadnought*, constructed for the Admiralty by Vickers-Armstrongs (Shipbuilders) Ltd., was launched last October.



3 *The Pullmax quick beveller shown by Alfred Herbert Ltd.*

Yates Plant Ltd., a division of Baker Perkins Ltd. operating as a separate entity, were exhibiting a wide range of welding manipulative equipment associated with the welding industry.

One of several new patented features being displayed on Rotator sets is the automatic Anti-Creep device, which is controlled electronically, by a scanner, and automatically ensures that the vessel does not spiral off the Rotator rolls.

Two of the new Yates Twin-Pillar columns with retractable booms were operating, complete with automatic welding heads.

Rotators from 100 lb. to 100 tons capacity were displayed and demonstrated. The smaller units are based on the Autroset quick-setting principle and the larger machines are based on the heavy-duty design well proved on nuclear power contract work.

Of special interest to those concerned with the fabrication and welding of large boilers, etc., was an accurate scale model of the Trawsfynydd Site Workshops where the Trawsfynydd 350-ton heat exchangers are welded.

Other displays

The main exhibit on the stand of the *English Electric Co. Ltd.* was a complete British Railways Type 1 diesel-electric locomotive. Total weight is 72 tons and length 46 ft. 9 in. Powered by an eight-cylinder diesel engine, type SVT, it develops 1,000 h.p. One of these locomotives, the first of 20 ordered in 1955, locomotive D.8000, was the first main-line diesel to go into service under the modernization plan. Altogether English Electric is building 128 of them for British Railways. Main use is for suburban and transfer duties.

The other traction exhibit is a sectioned and working model of British Railways Type 4

(2,000 h.p.) diesel-electric locomotive. The company—the only one to be building all five types under the modernization plan—is building 200 type 4s.

The evolution of the internal combustion engine was the theme of the display by *Shell-Mex and B.P. Ltd.* on the stand of Shell Industrial and Marine Lubricants. This theme has been adopted to mark the centenary of the conception by Otto in 1861 of the four-stroke cycle principle and to show the evolution of the engine through the ensuing 100 years.

The theme was developed in a mural with panels showing the originators of the principles as well as modern applications of modern compression-ignition engines in industry and transport.

As alloy-steel makers, forgemasters, heavy engineers and steel founders, *Firth Brown Ltd.* were illustrating a representative range of all their products.

These included carbon and alloy-steel forgings for marine turbines and transmission gears and power generation, forged-steel cylinders, rings and other forgings for aircraft, gas-turbine and jet-propulsion units and forged-steel die blocks.

Their forged-steel rolls for the rolling of ferrous and non-ferrous sheet and strip, precious metals, plastic, etc., are supplied in the fully-hardened condition up to 36 in. dia., 17½ tons in weight, and back-up rolls up to 56 in. dia. and 45 tons in weight.

Whilst copper and its alloys readily lend themselves to fabrication by practically every known manufacturing process, the *Copper Development Association* selected two specific examples for featuring on their stand.

Copper and its alloys are particularly suitable for extruding, and some of the many sections which can be produced by this process were displayed, together with samples of typical components machined, forged or hot pressed from copper or copper-alloy extrusions.

An exceptionally wide application of certain copper-base alloys is to be found in the fabrication of heat-exchangers and condensers and where, in most instances, tubes must be welded to tube-plates. Of particular significance in this respect is a recently-developed semi-automatic welding gun, operating on the inert-gas and tungsten-arc process.

The Plasma flame spray gun was exhibited for the first time in this country by *Metco Ltd.* Plasma now makes it possible to deposit as a coating many types of metals, refractories and oxides previously denied research and design engineers. Materials that can be sprayed include chromium, cobalt, molybdenum, tungsten, chromium carbide, tungsten carbide, rare earth oxides, titanium oxide, calcium zirconate and, in fact, most materials that do not decompose when melted. These materials, applied with the type MB Plasma flame-spray equipment, give a dense coating and a high degree of bond to the base metal. The equipment has been designed for development work in the jet- and rocket-motor fields, missile work, nuclear and electronic industries and research work into applications involving the use of these high-temperature materials.

Edgar Vaughan & Co. Ltd. featured their fuel-oil additives, cleaning solvents, etc., for marine uses, oils for metal working and products for heat treatment.

Hedin Ltd. showed examples of industrial electric heating equipment, including ovens, furnaces, elements and a new range of small-capacity ovens, suitable for heat treating small components.

A special exhibit showed how Hedin equipment serves the electrical industry and featured the electrical products which are processed: Rubber and epoxy-resin castings, together with electric motors and transformers which are cured in their ovens; and die-cast control gear parts produced by their furnaces.

Of particular interest to the communications industry were the humidity and low-temperature environmental test cabinets. These are for testing electronic components and cables under extreme climatic conditions. The cold cabinet is a new product of completely novel, competitively priced, design, which provides temperature cycles from −70°C. to +150°C.

Pantak Ltd., of Vale Road, Windsor, Berks., were exhibiting the full range of Balteau portable industrial X-ray units which they market, in addition to details of the range of mobile equipment which they produce. Also on show were a selection of radiographs taken by equipment ranging from a small, lightweight, gas-filled unit of 150 kV. to a mobile industrial betatron of 18 MeV.

The portable Balteau range consists of two oil-insulated units of 140 and 200 kV. capacity and two gas-insulated units of 150 and 300 kV. capacity, both the 150- and 300-kV. units being produced in special forms for 360° being radiography as required, for example, in pipeline examination.

The Siemens 18-MeV. betatron which the company market in the U.K. has been developed for mobile use in the examination of steel thickness greater than 4 in. One of the particular features of this unit is the use which may be made of a 'hot state' radiographic technique which eliminates the need for alternate cooling and heating of the work-piece and thus eliminates the danger period when flaws may develop. A further feature is the use of an enlargement technique with this unit in which the most minute flaws, beyond the range of any other

continued on page 252

Non-destructive testing of welded tubing

In 20 years Republic Steel Corporation has produced millions of feet of resistance-welded tubing. In the course of these years of production they have examined many types of non-destructive tests —hydrostatic, radiography, ultrasonics, magnetic particle and electromagnetic induction—and studied the advantages and limitations of each of these for their requirements.

No non-destructive test currently used on tubing is infallible. No test unerringly detects all the defects that should be rejected. But the errors made by the different tests differ in varying degrees or scope since they operate under different basic principles. Because of these inherent errors, complete quality assurance can be obtained only from the use of a combination of techniques. But this ultimate quality assurance is not economically practical, except perhaps in highly critical atomic energy applications.

The producer who decides to use non-destructive testing must take a practical compromise, choosing the method that gives him the best combination of low cost and high insurance against product failure. Low cost depends on high-speed operation, low capital investment and insensitivity to harmless variables. Insurance against failure depends on high sensitivity to genuine rejectable defects and mechanical rejection independent of the operator's judgment.

The method that has been found to give the best combination of advantages for 'looking through' welded tubing is Republic's electromagnetic induction method—Farrowtest. More than 57,000 miles of tubing have been examined by this method.

In Farrowtesting, an electrical current is induced in the pipe or tube by a solenoid coil. Defects cause changes in the induced current which affect the associated detection circuit. The method provides sensitivity to small defects, external and internal; high-speed operation; automatic signalling; adjustable sensitivity; and independence of personal judgment.

Widely used for many years on pipe and tube up to 4 in. dia., its use is now being extended to tubular products as large as 16 in. dia. The transition to larger sizes involves the solution of mechanical problems associated with handling of massive pipe and electrical problems evolving from a new set of variables and the requirement of a new type of discrimination. But these problems seem well on the way to solution.

Hydrostatic test

The hydrostatic test is the best-known and most widely used non-destructive test for tubular products.

Experience long ago revealed that many harmful defects pass the hydrostatic test without detection. To establish quantitatively the size of defect that can pass certain hydrostatic tests, a series of artificial defects were tested. Slots were milled in sections of flat-rolled steel, which were then formed into tubes and electrically welded. The tubes were then drawn down to smaller diameters, until the milled slots were tightly closed. Numerous hydrostatic tests were then made, with applied pressures producing fibre stresses ranging from 3,750 to 47,000 lb./sq. in. Pressure was maintained for periods much longer than those required in any specifications. Here are some of the findings:

1. Defects 90% through the tube wall and as long as 1·5 in. may be missed by certain widely used hydrostatic test specifications.
2. Defects 50% through the tube wall and as long as 7·7 in. may be missed by certain widely used hydrostatic test specifications.
3. Large defects may be missed, even with test pressures as high as 8,000 lb./sq. in. For example: defects 2·7 in. long and 46% through the tube wall; 1·4 in. long and 94% through the wall; 1·3 in. and 43% through the wall. All of these were in 1·75 in. o.d. × 10 gauge tube.
4. Tubes may fail in low-pressure service after passing an 8,000 lb./sq. in. hydrotest of short duration. The indication is that the hydrotest sometimes increases the chance of subsequent failure.

Radiographic test

Radiographic methods, such as X-ray and gamma ray, depend on the penetration of the tube wall by high-frequency radiation, and the sensitivity of film or a fluorescent screen to the H.F. energy that gets through the wall. The indication on the screen or film is sometimes called a shadowgraph.

If the film is used, the time required for development and the overall cost usually rule out use of this method for 100% inspection of tubular products. Use of a fluorescent screen or a television receiver eliminates the time delay, but requires constant observation and interpretation of the shadowgraph by the inspector.

There is another drawback to the use of radiographic methods for the inspection of electrically

welded tube or pipe. Registry of a defect by radiographic means depends largely either on the absence of material or the presence of material whose energy transmission properties are markedly different from those of the material the pipe is made of. To affect the shadowgraph, the path of the radiation must be through sufficient foreign matter to change the degree of energy absorption in that path; if the defect does not affect the absorption of energy, the shadowgraph will not be affected.

In electrically welded tube or pipe, large defects may frequently have little or no effect on the tube's capacity to absorb radiographic energy. The amount of foreign matter, air, gas, oxide, etc., trapped in the defects is so small that the defect is practically two-dimensional. The defects are usually in a radial and longitudinal plane, with practically no dimension in the circumferential direction.

The net effect of this condition is that absorption of radiographic energy is practically unaffected, and no evidence of the defect appears on the shadowgraph.

Magnetic particle test

With this method, the article to be tested is magnetized and magnetic particles—dry or suspended in liquid, sometimes fluorescent—are applied. Discontinuities become new magnetic poles or centres of magnetic attraction, and draw the particles to the defective area, making their detection by visual methods possible. If the particles are in a fluorescent medium, ultra-violet light is used to make their detection even easier.

This method is widely used in industry; as a matter of fact, in some applications it is the only non-destructive test that can be used successfully. However, since it is sensitive primarily to defects that penetrate the surface, it has serious drawbacks for the testing tube. Sensitivity to sub-surface defects drops rapidly as the distance from the surface increases, and a defect of rejectable size, which may be readily detected on the outer surface, is likely to go undetected on the inner surface.

This test method depends on the vigilance and interpretation of the inspector. Devices for automatic observation and evaluation have been built, but have not been widely used. But, even with these improvements, we believe the method will be limited mainly to surface defects.

Ultrasonic test

Ultrasonic methods have shown rapid growth in application to tube and pipe testing. A high-frequency mechanical vibration is projected into the piece under test, and detects the presence of a defect by reflection of energy from it. Like radiographic inspection, it is valuable in detecting internal defects, and has achieved some outstanding results.

Two general methods are used—contact and immersed. In the contact method, there is direct contact between the high-frequency vibrating source or its mounting and the piece being tested. In the immersed method, the vibration passes from the source to the test piece through a coupling liquid.

Rapid progress has been made in the application of both methods to tube testing in the last three years. Signals from harmless variables have been reduced. This permits better discrimination between defects and harmless variables.

Evaluation of the size of a defect will always be a problem with ultrasonic testing, but it is possible in some instances even now to use the signal to appraise the size of a defect. Undoubtedly, improvements will be made in this area.

Electromagnetic induction test

Farrowtesting and other magnetic induction methods depend on the induction of an electrical eddy current in the pipe or tube, whose electrical characteristics are changed by defects in the material. These changes are in the induced current, the magnetic field around the defect, and the current, voltage and phase relationships in the detection circuit. The current is usually induced by alternating current flowing in a solenoid-type coil surrounding the tube. The frequencies used range from 60 to 200,000 c./s., with the higher frequencies used for small-diameter, light-wall, non-magnetic materials such as stainless steel.

When testing magnetic materials such as carbon steel, it is usually necessary to saturate the tube magnetically to increase the sensitivity to genuine defects without increasing the sensitivity to the numerous harmless variables usually present in most tubes. This is done usually by surrounding the tube and its a.c. solenoid with a d.c. solenoid generating a powerful magnetic field. A water-cooled, low-voltage, high-current coil arrangement has been found most satisfactory for production use.

The sensing device consists of another coil or group of coils located near the tube or between the sections of the a.c. solenoid. The output of the detector coil assembly is evaluated by an electronic circuit, whose characteristics depend largely on the type of defect separation required.

Early in the development of the Farrowtest method, it became apparent that sensitivity to defects was not difficult to achieve. However, the utility of a non-destructive test cannot be measured by sensitivity alone. High-sensitivity that produces signals for minute defects also produces signals for many harmless variables such as grain size, stress concentrations, minor inclusions, etc., that

may not be a good cause for rejection of pipe or tube. So perhaps even more important than sensitivity is discrimination.

Complicating the discrimination problem is the fact that a defect that is objectionable for one application of the tube may be completely acceptable for another. For instance, a pinhole leak in a tube carrying liquid may be disastrous regardless of the soundness of the surrounding metal; but, in a structural tube, the pinhole itself may be of no importance.

In calibrating the machines for production use standardized calibration tubes with artificial defects are used. Although the electrical effect of an artificial defect is not the same as that of a natural defect of the same size, careful development of the electrical relationships between natural and artificial defects for the particular circuit permits the use of artificial defects for calibration.

With the help of calibration tubes, all machines can be made to work the same way. A tube or batch of tubing tested at different times and on different Farrowtest equipment give identical signals. Thus, test results are uniform and repeatable.

A typical detector panel includes such defect indicators as a signal light, an oscilloscope and an ammeter. These devices are used mainly in the preliminary adjustment of the test and in trouble-shooting. In production, the entry of a defect into the test area stops the tube for visual inspection or actuates a paint spray which marks the defect area.

The conclusion reached by Republic Steel after years of study and analysis is that their electromagnetic induction method not only fits more conveniently into the production line but also provides more accurate discrimination between genuine defects and harmless variables. Like all other non-destructive tests, it is not infallible, but the overall capacity of the method to make the desired discrimination on a measured and calibrated basis is considered far superior to that of other methods.

Engineering, Marine, Welding and Nuclear Energy Exhibition

concluded from page 248

X-ray unit or accelerator, are readily detectable.

Two additions to their range of mercury-in-steel temperature controllers have been introduced by the *British Rototherm Co. Ltd.*, Merton Abbey, London, S.W.19.

The first, now in production, is a three-stage controller to operate on rise or fall of temperature. It can be set, if necessary, to show a warning light, followed by an alarm bell, and with a complete cut-off of plant at the third stage. It can also be set to give a continuous warning.

The second new unit, now ready for production, is a temperature recorder-controller which will control between fixed differentials and record the temperatures on a chart. It consists of a chart temperature recorder with the addition of hand-set electrical contacts which operate a self-contained plug-in electronic relay unit for on/off control.

Deva metal, now being manufactured in Britain by the *Universal Metallic Packing Co. Ltd.*, is a homogeneous and non-porous solid, made by compacting natural or colloidal graphite powder with primary or alloyed metal powders, is claimed to be the only metal which is permanently self-lubricating, irrespective of wear, over a wide range of temperatures. It owes this quality to the graphite film that forms on the contacting metal surface under friction, allowing it to withstand higher temperatures and pressure/velocity factors than porous bearing materials impregnated with grease or oil.

Deva metal is especially suitable for use on bearings where operating conditions might lead to the breakdown and dispersal of conventional lubricants or where the presence of oil or grease might result in contamination of the product being handled. Various grades of bronze, brass and iron are used as the metallic constituent, to cover operating temperatures between −201°C. and 592°C. The material is easy to machine and, in spite of its graphite content, it possesses useful mechanical properties.

Strip and tin mill equipment

The Wean Engineering Co., Inc., of Warren, Ohio, has established a new company in Great Britain—Wean-Miles Ltd.—to furnish strip and tin mill equipment of Wean design.

This new company will assume the manufacture and sale in Great Britain of many items of equipment designed and sold by the Wean Engineering Co. in the U.S.A. and throughout the world. The Wean Engineering Co.'s designs will be maintained at all times by Wean-Miles Ltd., who will adapt Wean (U.S.A.) drawings to British standards.

The Wean Engineering Co., working through Wean-Miles Ltd., has at the present time under construction equipment for the British steel industry, including one high-speed electrolytic tinning line, two continuous strip pickling lines, two high-speed shear lines, one high-production continuous strip annealing line for tinplate and a slitting line. This work is being carried out in Great Britain under the supervision of Wean engineers.

The head office of Wean-Miles Ltd. is at 76 Cannon Street, London, E.C.4, England.

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Our new High Speed Drum Sanders make all other types obsolete.

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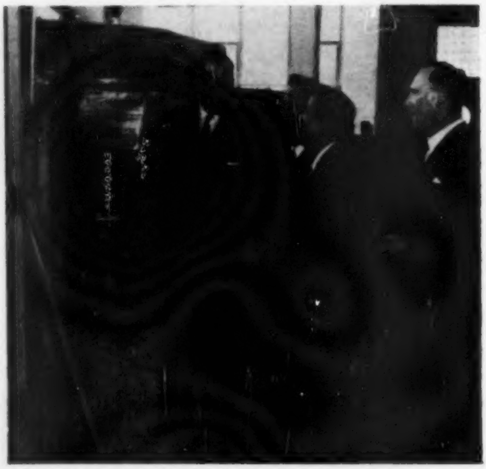
NEWS

Chinese visitors to Garringtons

As the largest manufacturers of forgings in Europe, producing over 100 million forgings annually, it is natural that Garringtons Ltd. (Bromsgrove and Darlaston) should receive many interested visitors from overseas, and recently they were pleased to entertain at their Bromsgrove factory, Mr. Chu Kang-Chieh, the Deputy General Secretary to the China Council for the Promotion of International Trade, and Mr. Tao Li-Chung, B.Sc., a Technical Consultant to the China Council for the Promotion of International Trade. They were accompanied by Mr. Chandler, of the London Export Corporation Ltd.

Mr. Chu Kang-Chieh is responsible for the broad industrial appreciation and Mr. Tao Li-Chung is a technical consultant, primarily an electrical engineer, and their joint mission is to explore, during the month they spend in this country, the sort of equipment which British industry has to offer and which will be of use to the Chinese expansion programme under the new 5-Year Development Plan. This visit will result ultimately in specific enquiries being sent to groups of companies, for particular and specific items of plant and equipment. The visitors expressed particular interest in the Company's induction-heating equipment, stating that there is a continuing expansion of hydro-electric power in China, which would enable such modern equipment to be successfully employed.



Left to right: Mr. K. L. Moon, Mr. Chu Kang-Chieh, Mr. Tao Li-Chung and Mr. Chandler

Lamberton horizontal forging machine
The first arm and roller of the manipulator is at left of picture

Heavy horizontal forging machine at Stewarts and Lloyds

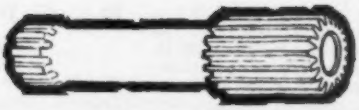
Stewarts and Lloyds have recently commissioned a new horizontal forging machine at their Mossend Tube Works in Lanarkshire. The machine was designed and manufactured by Lamberton & Co. Ltd., of Coatbridge.

The prime purpose of the machine is to upset the ends of heavy steel tubes used for lining deep oil wells. The upset of the ends enables a screw thread to be cut on the tube, male at one end, female at the other. Thus lengths of tubes are screwed into each other without the need of any coupling piece.

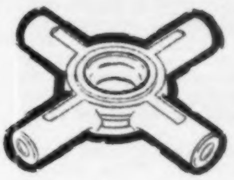
Tubes up to 10 in. dia. can be forged and consequently the machine is a very heavy one, having a total weight of about 300 tons and being capable of exerting a forging pressure of over 2,000 tons. The manufacturers believe that this is larger than any similar machine yet built in Europe.

Because of its size, the main frame was made in two pieces, one piece over 100 tons in weight. The side slide which carries the gripping dies is operated through toggles by cams from the main crankshaft. This slide and the main slide are guided between anti-friction liners with automatic oil lubrication.

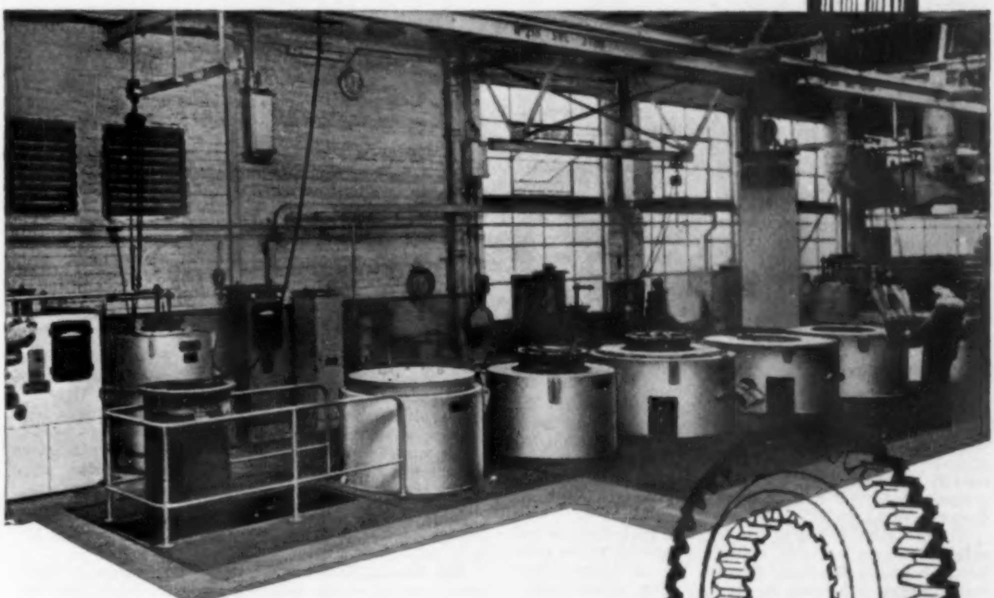
The forging operation is made by a series of punches carried in the main slide which is driven directly from

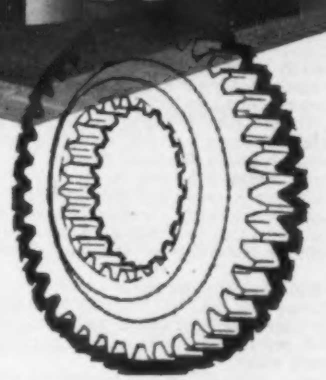


WILD BARFIELD



GAS CARBURISING





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WB.93

the crankshaft. The crankshaft is turned by a 250 h.p. motor through vee-belts and reduction gearing. The stroke of the main slide is especially long being 30 in.

Since the operation of the machine requires one stroke only at a time, a multiplate clutch and a disc brake are employed. These units are also designed and manufactured in Coatbridge and have been specially developed to stand up to the exacting duty of starting and stopping a large mass of machinery, some 15 times a minute. Both the clutch and brake are air operated and so arranged that should there be a failure of air or electric power, the clutch disengages and the brake is applied. Other safety devices to guard against overloads and misuse are incorporated.

The tubes to be processed are delivered from the end heating unit on to manipulator rollers. These raise the tube to the level of the first die position and then move it forward into the dies. After the first forging operation the manipulator lowers the tube to the second die position and so on. The tube is thus manipulated through the forging cycle entirely by mechanical power.

Enquiries should be addressed to the Lamberton subsidiary company, Eumuco (England) Ltd., 26 Fitzroy Square, London, W.1 (Euston 4651).

A further extension to the covered area of Faulkners Ltd., Colnbrook, Bucks.

A further extension of covered area at Faulkners Ltd., manufacturers of drop forgings, has recently been completed by E. W. Tyler & Co. Ltd., precast concrete engineers, of Tonbridge and Manchester. The new extension follows two other buildings erected by Tylers in 1959, which then doubled Faulkners' existing heat-treatment department.

The newly completed building will house additional equipment for the heat treatment of drop forgings, shot blasting machinery and various inspection processes together with a dispatch bay. Faulkners Ltd. are an associate company of the London electro-forging producers, Messrs. Omes Ltd., Beverley Works, Barnes, London, S.W.13.

G. A. Platon Ltd., established four years ago, has now removed to a large modern factory at 281 Davidson Road, Croydon.

The range of FLOSTAT self-acting flow controllers for liquids and gases pioneered by the company has been widely extended and now includes miniature models for analytical work and burner control, as well as industrial models up to 6-in. pipe size, both of the precision and poppet-valve type and of a butterfly valve design for flow-governing duties.

To fill a notable gap in the range of automatic control valves currently available, an agency agreement has been concluded with Research Control Inc. of Tulas, Oklahama, which will bring to the U.K. the MINIM valves, which are already very popular in the U.S.A. for pilot and research work. A range of indicating-flow meters—the GAPMETER—has been introduced which can be fitted with the FLOSCAN photo-transistor alarm switch.

Two more for the road!

During the past 18 months, 54 Morgan basin tilting furnaces have been sold to modern foundries for the fast bulk melting of a wide range of aluminium and copper-based alloys.

The activities of the Crucible and Furnace Departments of the Morgan Crucible Co. Ltd. are now carried on by Morganite Crucible Ltd., Norton Works, Woodbury Lane, Norton, Worcester, but their furnace demonstration and test foundry will remain at Battersea where visits from customers are always welcomed.

PEOPLE

THE FIRST AWARD of the Sir Walter Puckey Prize was made to **Mr. L. C. Lambert,** DIP.TECH.(ENG.), at a meeting of the Wales Region of the Institution of Production Engineers, held at the Welsh College of Advanced Technology, Cardiff, on the evening of March 10, 1961. The presentation was made by Sir Walter Puckey, past president of the Institution.

The Sir Walter Puckey Prize is an annual award of £50, open to first-year students taking diploma in technology courses in any branch of engineering in any college in England and Wales. It is made for an outstanding project in a production engineering subject.

Mr. Lambert was a final-year student at the Welsh College of Advanced Technology during the session 1959-60. He obtained the Diploma in Technology (Eng.) in September, 1960, with second-class honours, and his project was on 'friction welding.'

Mr. W. S. Walker, PH.D., M.SC.(TECH.), has joined Campbell, Gifford & Morton Ltd., consulting engineers, of 52 Queens Road, Weybridge. In 1936 he went to the Brown Firth Research Laboratories and was seconded for three years to the Vitkovice Works in Czechoslovakia. He then returned to Firth Brown's works in Sheffield, after a period of service with the Admiralty during the war.

Dr. Walker spent ten years reorganizing and largely rebuilding the Round Oak Steel Works, resigning at the end of 1960. In 1959 he led a technical mission to Russia. He has served as a member of the BISRA Council and is on several of its technical committees. He is an honorary member of the council of the Iron and Steel Institute.

Mr. Raymond V. Ely, M.I.E.E., M.I.MECH.E., a specialist in the field of the application of electrical transformers to arc welding and X-ray technology, has been appointed consultant to Gresham Transformers Ltd. Mr. Ely will advise the company on the needs in the fields of arc welding and X-ray technology.

Steel, Peech and Tozer, a branch of the United Steel Companies Ltd., announces the following metallurgical appointments.

Dr. B. B. Hundy, chief research metallurgist, is to become chief metallurgist; **Mr. W. Ash,** at present chief works metallurgist, will become deputy chief metallurgist; and **Mr. H. A. Longden,** assistant chief works metallurgist, is to be works metallurgist.

Alcan Industries Ltd. announce the election of two new directors to their board, Mr. A. A. Bruneau and Mr. R. J. Moyse.

Mr. Moyse, who was appointed chief financial officer and treasurer of the company last year, joined the Aluminium Ltd. organization in 1951, serving with Aluminium Securities, Montreal, and latterly as secretary-treasurer of the Indian Aluminium Co. Ltd.

Mr. Bruneau joined Alcan Industries (then Northern Aluminium) last year as secretary. His career with Aluminium Ltd., which began in 1949 with Aluminum Co. of Canada, included an earlier period with Northern Aluminium, and he was latterly with Aluminium Secretariat, Montreal.

It has also been announced by Alcan Industries Ltd. that **Mr. C. J. Buchanan-Dunlop** has been appointed manager of the Birmingham Area Sales Office in succession to **Mr. D. W. Taylor,** who is to take over management of the London Area Sales Office later this year. For the past six months Mr. Buchanan-Dunlop has been assistant manager in Birmingham.

Electrical Aids in Industry *Data Sheet* **No. 17**

Canteen Catering

As in every other industry, the main factors governing the economics of the catering business are: quality of product, cost of production, and well-being of workpeople. Electricity measures up well to these three essential factors.

The outstanding virtue of electricity is better cooking, particularly in roasting and pastry ovens where high quality is more easily maintained than in ovens using other forms of heat.

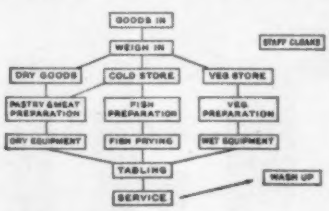
The cost of production varies somewhat with the type of food and the size of the establishment, but is usually between $\frac{1}{4}$ and $\frac{1}{3}$ of a unit of electricity per meal. Cleanliness of electric cooking is axiomatic and provides better working conditions for the staff.

The actual size of the kitchen is influenced greatly by its shape and by the number of people catered for, but a rough guide is as follows:

Kitchen to deal with up to:	*Size:*
100 persons	5-6 sq. ft. per person
100-250 persons	4-5 sq. ft. per person
250-1000 persons	3-4 sq. ft. per person
over: 1000 persons	3 sq. ft. per person

Design

Where the kitchen is designed from the start for the full use of electricity, planning is simplified as the equipment can be placed where it is required without reference to the need for flues.

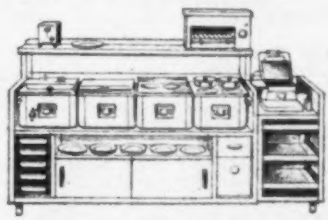


If an existing kitchen is already using other types of cooking equipment, however, electrical equipment can still be introduced item by item to bring increasing benefits.

Quick-service Equipment

The popularity of the quick-service establishment where the food is cooked at the service counter in the full view of the customer is steadily growing, and this type of catering can readily be provided in the canteen by the installation of a Back Bar cooking unit, installed behind a section of the service counter.

The popularity of the mid-day joint and two vegetables is on the wane and the really up-to-date canteen should provide the welcome alternative of fresh food cooked on the spot.



Electric Catering Equipment

Electric catering equipment covers every single kitchen activity and some of the appliances in common use are:

COOKING. Ranges, boiling tables, steaming, roasting and pastry ovens, vegetable boilers, fryers, griller/toasters.

SERVICE AND WASHING-UP EQUIPMENT. Bains-marie, hot cupboards, washing-up machines for the larger kitchen and sterilising sinks for the smaller, refrigerated cold-service counter and display cabinets, soda fountains.

PREPARATION. Mixing machines with attachments for chopping and mincing, etc., potato peeler, slicing machine.

QUICK-SERVICE EQUIPMENT. Infra-red (contact) grill, automatic toaster, griddle plate, automatic fryer, boiling plates, soup heaters, etc., and, of course, the indispensable refrigerator.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. Tel: TEMple Bar 9434.

Excellent reference books on the industrial and commercial uses of electricity are available—" Electric Commercial Catering Handbook " (5/-, or 5/6 post free) is an example.

E.D.A. also have available on free loan in the United Kingdom a series of films on the industrial uses of electricity, including commercial catering. Ask for a catalogue.

12799/4

CUT HERE

High- and low-level Proximitor

The Proximitor unit of the Electronic Machine Co. Ltd. has been designed to provide an inexpensive, sensitive and reliable capacity-operated relay of robust construction that can be used over a very wide variety of industrial and laboratory applications and, due to the use of a transmission-line technique, very long leads can be used; even lengths of up to 100 yds. can confidently be used without loss of stability or interference from the presence of metal girders and the like along its run.

This sensitivity and stability makes it possible to use the unit for counting on conveyors when speeds of up to 1,000/min. can be obtained with relay operation of electro-mechanical counters and, where higher speeds are required, a pulse output is available for operation of any of the Electronic Machine Co. Ltd.'s standard range of Batchcounters, when speeds of up to 12,000/min. are possible.

The probe itself can be supplied either of stainless steel or sheathed in plastic, suitable for any application and, in the case of use for level control, is threaded ½ in. B.S.P. for insertion in tank and hopper sides or for installation in the top of a container where B.S. nozzle flanges are used.

Particulars of either the low-level unit (model No. PRO1L) or the high-level unit (model No. PRO1H) may be obtained from Electronic Machine Co. Ltd., Mayday Road, Thornton Heath, Surrey, England.

Developments in Batchcounting

So many and varied are the uses to which Batchcounters are put that Electronic Machine Co. Ltd. have now redesigned their units to provide a more flexible form of basic 'off-the-shelf' type of instrument.

By the inclusion of the necessary stampings and fixing lugs, together with a comprehensive printed circuitry, it is possible to complete the basic unit in a few minutes by including the necessary component to meet the requirements of the stated application.

Design of circuitry is such that the unit can be easily modified to accommodate such applications as dual outputs, time delays, microswitch, photocell and magnetic pick-up input devices, speed of count being up to 20,000/min.

Classified Advertisements

FIFTEEN WORDS *7s. 6d.* (minimum charge) and *4d.* per word thereafter. Box number *2s. 6d.* including postage of replies. Situations Wanted *2d.* per word.

Replies addressed to Box Numbers are to be sent, clearly marked, to Metal Treatment and Drop Forging, John Adam House, John Adam Street, London, W.C.2.

SITUATIONS VACANT

FOREMAN REQUIRED for production department of North Midlands engineering works comprising Drop Stamping with some repetitive machining and assembly. Age preferably 35-40 years. Superannuation and profit-sharing schemes.—Box No. B721, c/o Walter Judd Ltd., 47 Gresham Street, E.C.2.

SITUATIONS WANTED

QUALIFIED CHIEF METALLURGIST (A.I.M.), in late twenties, with wide experience including steel forging, heat treatment and general engineering metallurgy, seeks position with progressive company as metallurgist, consultant metallurgist or technical representative. Box No. QC139, METAL TREATMENT AND DROP FORGING.

MACHINERY FOR SALE

COVENTRY CLIMAX FORKLIFT TRUCKS ! ! ! A choice selection of electric, petrol and diesel models. From 1,500 lb. to 4,000 lb. capacity, 9 ft. to 12 ft. lifts. Full details, photographs and prices from Speed Electrics, Dept. MTDF, Church Street, Basford, Nottingham. Tel. 75716.

CAPACITY WANTED

WELL-ESTABLISHED MIDLAND FIRM OF AGENTS desire to contact drop-forging company with available capacity. Box No. WE138, METAL TREATMENT AND DROP FORGING.

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